Message from the Conference Chair

I am pleased to be able to bring you the Proceedings of the Eighth Research in Engineering Education Symposium (REES 2019). REES is the biennial symposium of the Research in Engineering Education Network (REEN), an international community of scholars interested in conducting high quality work in, and advancing the field of, engineering education research. One of the goals of REEN is the development of meaningful collaboration between engineering education researchers working in different parts of the world. As such, REEN partnered with SASEE, the South African Society for Engineering Education, for a joint biennial conference in 2019. These proceedings are therefore also the Proceedings of the Fifth Biennial Conference of the South African Society for Engineering Education.

The logo for the symposium is an unfinished suspended highway, an artefact that is visible near the entrance to the Victoria and Alfred Waterfront in Cape Town, a large tourist complex and the venue for REES 2019. If you follow the arc that this road describes you will see on the other side of the intersection the matching section of incomplete freeway. What is clearly needed is a bridge joining these two parts which speaks to the conference theme: making connections. Just as an engineering project joining these to pieces of highway would mean better traffic flow, the logo symbolises the hope that the education project of REES 2019 will be a productive meeting of minds for engineering education researchers from all over the world for a better flow of ideas on engineering education.

There are other ways that the symbol of an unfinished bridge speaks to REES 2019. While urban legend has it that the highway could not be completed due to a calculation error by the civil engineer, which halted construction in 1977, the real reason is that the city ran out of money at the time and traffic congestion has not been bad enough to warrant the completion of the project since then. This vividly demonstrates that despite the best engineering design skills, the messiness of the real world often frustrates our engineering intentions. In the same way, the problems that we face in education often require us to reach outside of our engineering toolbox and draw on other forms of knowledge to engage with the messy real world and the human beings who are at the heart of the education process.

Finally, in her description of some of the complexities of this failed project, Kane (2011) demonstrates that transport planning is not a neutral process but a highly politicized one. She argues that ‘...the seemingly neutral urban road infrastructure that we now live with have embedded in them their social and political histories’ (p. 138). Here she was referring to how the politics of apartheid shaped urban planning in South Africa and how this history remains embedded in the urban landscape, including the transportation systems. This is particularly pertinent to South Africa’s education system but can certainly be applied more generally: ‘When considering what to do with these political artefacts from the past, we would do well to reflect on their histories, and on what politics are embedded in them’.

Bruce Kloot

Reference (the paper is included in the appendices for interest)
Conference review procedure

These proceedings are a published record of the Eighth Research in Engineering Education Symposium (REES 2019), also the Fifth Biennial Conference of the South African Society for Engineering Education (SASEE). The purpose of these proceedings is to disseminate original research and new developments within the discipline of engineering education.

All submissions accepted for this symposium went through a multiple-review process prior to publication. Authors initially submitted one-page abstracts which were double-blind reviewed by two or more reviewers. Based on the outcome of this review, authors were invited to either develop this into a full paper or submit a three-page extended abstract taking into account the reviewers’ comments. Authors of the submissions in both of these categories were eligible to present their work at the symposium.

While the extended abstracts did not undergo another round of review, the full papers were further reviewed by two reviewers in a double-blind peer review process. Submissions that required relatively minor changes were encouraged to take into account reviewer comments to develop their paper towards a final submission. However, there were six submissions that required substantial changes and the authors of these submissions were required to revise and resubmit with a separate document indicating the changes that were made before the submission was accepted as a full paper.

The reviewers for this two-stage process were drawn from REES 2019 authors, REEN, SASEE, the Centre for Research in Engineering Education (CREE) at the University of Cape Town and students attending the 2019 winter school of the Australasian Association for Engineering Education (AAEE).

The rejection rate for the first round of review was 5% with 26% of the submissions being invited to submit extended abstracts and 69% invited to submit full papers. In the second round of review, the rejection rate was also 5%, but with only 68% of those invited to submit full papers taking this forward to a final submission.

**REES 2019 Organising Committe (UCT)**

Dr Bruce Kloot (Chair)
Dr Ashish Agrawal
Emer Prof Trevor Gaunt
Dr Corrinne Shaw
Dr Nicky Wolmarans
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Volume I: Full papers
How to make pre-college STEM programs and industry partner relationships successful: a systematized literature review of industry mentoring

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Abstract: Industry engagement in pre-college STEM programs extends from grants to informal (out of school time) activities including industry involvement by mentoring. Despite these well-meaning investments, present metrics seem to demonstrate slow progress towards positive demographic changes in STEM fields, especially for disenfranchised populations. The objective of this paper is to examine STEM programs supported by industry partnerships within pre-college informal STEM environments. This paper uses a systematized literature review to evaluate 121 peer-reviewed articles published in the last thirty years about mentoring in pre-college informal STEM programs. In this review, we identified themes related to mentoring models, increasing gateways to career participation, and increased awareness because of the participation of industry mentors. The findings provide recommendations for implementing and supporting mentoring initiatives with industry partners in pre-college informal STEM settings. Future work may include how partnerships with industry can support mentoring in informal STEM programming for pre-college students.

Introduction

Industry outreach in the United States can be traced back to the progressive era (Allen, 2003). However, the effectiveness of industry outreach activities on pre-college STEM programs and what training is needed to prepare industry professionals to deliver effective outreach has not been reviewed extensively. These programs extend from financial grants to informal activities including industry involvement by volunteering and mentoring. Despite these well-meaning investments, present metrics display only slow movement towards validating positive demographic changes in STEM fields or show a slowing of STEM associated career interests in student groups, especially in disenfranchised populations (Kuenzi, 2008). This slow movement does not mean that the industry activities have served no benefit but provides an opportunity to investigate what approaches are working or not working so well. Reviewing all industry outreach activity would be a significant task, which is why we chose to focus on one form of industry outreach activity—mentoring. Mentoring within pre-college settings “emphasizes developing the ‘whole person’ over relatively long-term horizons...” (Sosik, Lee, and Bouquillon, 2005). Due to the focus on the ‘whole person,’ research suggests that quality mentoring relationships have positive effects on pre-college students. These effects include but are not limited to promoting personal growth, academic development, and making professional connections (Schweinle, Meyer, and Turner, 2006).
Mentoring is an avenue to provide professional role models to pre-college students and can be introduced to students at any stage in the education process, including as young as elementary. These professional role models can show the endless possibilities of a STEM career.

Government organizations have invested a significant amount of time, money, and other resources into STEM learning initiatives to aid in increasing student enrollment and growth in STEM fields to increase national competitiveness (Kuenzi, 2008). This belief is supported by organizations like the National Research Council who believe that engineering integration should be included in pre-college learning to help strengthen knowledge and awareness in STEM fields (National Research Council, 2013). However, because the enrollment gap persists in STEM programs, there is a significant obligation for STEM professionals and accompanying industry involvement in supporting STEM education programs to be successful (Davis and Veenstra, 2014). Opportunities for industry sponsors to apply their expertise in the new setting through informal STEM education programs for pre-college students should not only increase industry skill development (Caliguiri, Mencin, and Jiang, 2013) but also make STEM relevant and appealing to those being served (Seiler, 2001). Although little research has investigated industry-sponsored pre-college programs specifically, other research provides insights into the benefits of STEM programming. Smith (2015) finds a direct correlation between inadequate STEM education and African American students in STEM careers. These STEM skills include the ability to be able to inquire or ask relevant questions about a situation; problem solve circumstances, and ability to work independently (Felder, Woods, Stice, and Rugarcia, 2000). In support of this argument, connections are drawn between approaches correctly used in industry and the skill-set needed to participate in informal STEM programs for pre-college students. Tsui (2007) conducted a literature review to demonstrate research evidence on effective ways to increase diversity in STEM fields while presenting empirical support for three model intervention programs to inspire further research and discussion. In Tsui (2007)’s findings, mentoring programs have become more widespread and broadly seen implemented in a variety of different ways. Educated mentors have a lot to contribute to the education of children, and the effects of naturally forming informal mentoring relationships are more likely to be successful (O’Neill and Harris, 2004). Based on this, our immediate objective is to expand the perspective on the reasons informal mentoring with industry connections is vital for implementation in pre-college settings. Because of the methods in which academic publications are circulated, industry stakeholders may not be as knowledgeable of research best practices that could assist in their outreach investments. Therefore, the direct benefits of our research could include distributing the outcomes of the literature review with this critical “external” audience and industry stakeholder groups.

Furthermore, the culminating objective is to evaluate the extent to which best practices in evaluation is happening and is reported of industry-supported programs. These efforts contain the exploration and documentation of potential indicators, evaluation tools, and create a standard for programs with example case studies. With this information, informal industry supported outreach programs will have a stronger opportunity to develop more operational strategies to meet the needs of the students, organization, and industry partners while advancing STEM programming to increase diversity in the workforce.

**Scope and Research Questions**

The basis of this work is to expand the perspective on the justification for, and the amount of literature available on this critical and under-explored subject of informal industry led STEM programs. To position this literature review, we used the evidence-based PICO (population, interest, comparisons, outcomes) framework to form and assist search strategies for research (Schardt, Thomas, Owens, and Fontelo, 2007). We utilized PICO to frame the structure and develop the research questions. PICO also helped formulate a search strategy by identifying the fundamental concepts that should be present in an article that could
answer research questions. Using this framework, we could adequately scope the research inquiries to answer our research questions.

Table 1. PICO Framework for Review

<table>
<thead>
<tr>
<th>APPLICATIONS IN LITERATURE REVIEW</th>
<th>DESCRIPTION</th>
</tr>
</thead>
<tbody>
<tr>
<td>POPULATION</td>
<td>Data</td>
</tr>
<tr>
<td>INTEREST</td>
<td>What are the characteristics of the community? K-12 students</td>
</tr>
<tr>
<td></td>
<td>What is the focus? Capturing K-12 informal STEM mentoring approaches</td>
</tr>
<tr>
<td>COMPARISON</td>
<td>Is there a focus? Associate various mentoring approaches to evaluate which methods and tools maximize efforts</td>
</tr>
<tr>
<td>OUTCOMES</td>
<td>What is there to achieve? Informal STEM mentoring opportunities that benefit both K-12 students and industry</td>
</tr>
</tbody>
</table>

This systematized research focuses on pre-college informal STEM mentoring education to evaluate mentoring methods best for industry outreach through the PICO framework as outlined in Table 1. This inquiry centers on two research questions: 1) What mentoring approaches are used in informal K-12 STEM programs? 2) What are the benefits for industry in mentoring K-12 students?

Methods

The systematized literature review procedure described by (Borrego, Foster, and Froyd, 2014) was used for this study. We began by scoping the research question using the PICO framework to outline essential components of the study, see Table 1 (Schardt, Thomas, Owens, and Fontelo, 2007). Next, we selected databases, search terms (e.g., keywords/phrases), and inclusion and exclusion criteria for reviewing literature results. As a result, nine databases were chosen to guide the literature search.

- Begell Digital Portal: this database contains an expansive range of information on engineering
- EBSCOhost: ERIC—includes noteworthy articles in education.
- EBSCOhost: Business Source Complete—covers all business, including marketing, management, accounting, finance, banking, and others
- J-STOR Arts & Sciences: contains scholarly journals focused on social sciences, humanities, mathematics, and economics.
- ProQuest ABI/INFORM Collection: provides critical business and economics journals
- ProQuest Research Library: provides an assorted set of peer-reviewed journals.
- Sage Premier: provides access to an assortment of peer-reviewed journals
- Taylor & Francis Social Science and Humanities: database specifically on social sciences and humanities
- Wiley Online Library Journals: a collection of multidisciplinary areas including social sciences and humanities.

Search Phrases

Each database described above was used to search keywords/phrases in the title, subjects, and abstracts of the publications. We began by using the keywords/phrases to create a search string that extracted terms or phrases from the research questions developed using the PICO framework. Then we included any associated synonyms from a thesaurus in each database to ensure terms were consistent and transferable across databases. Our ultimate goal was to create a search string that required limited modifications from one database to another.
The most significant words we searched were “corporate,” “industry,” “mentoring” and “STEM.” However, due to the wide range of definitions of these words, a subset of word combinations was used to receive more focused results. These word combinations included:

“industry and pre-college STEM education,” “industry outreach,” “corporate outreach,” “corporate volunteering,” “industry and pre-college partnerships,” “industry volunteering,” “STEM volunteering,” “STEM mentoring,” “corporate mentoring,” “K-12 mentoring.”

This review focused on literature from 1986-2017 because this period aligns with the increasing popularity of industry and school partnerships. Additionally, to recognize further publications for enclosure in this analysis, citations appearing in relevant retrieved articles were also considered.

Selection Process

The database searches resulted in 121 articles that were selected based on the keyword criteria. Each article was transferred to Qiqqa, a research management software for academic researchers. Qiqqa identified and removed 30 duplicate articles. We first screened the literature by reviewing the title and abstract for relevancy, excluding 25 articles. Next, we applied the inclusion criteria mentioned below to narrow the search to 69 articles. After reviewing the literature against the exclusion criteria, we removed an additional 30 articles leaving 39 publications in our dataset. In these 39 remaining articles, we reviewed each to confirm the articles met the inclusion criteria, below, and addressed our research question.

Inclusion Criteria

This review focuses on research of articles that met the following criteria:

- Represented a peer-reviewed article published in a related journal
- The research focused on pre-college
- Industry-related articles included terms like a professional, corporation, management, business, firm, commercial, and corporate
- Concentrated on informal education settings
- Focused on business, STEM, engineering, science, technology, mathematics

Exclusion Criteria

Articles excluded in this systematized review included:

- A higher level of education (e.g., college and beyond)

Data Analysis

We reviewed the 39 articles that satisfied the inclusion criteria in three phases: initial examination, comprehensive examination, and recording of results. The objective of the initial phase was to discover universal characteristics in each article and then summarize. Next, the full text of the 39 articles was expansively reviewed and articles were then characterized based on the emphasis on answering the research questions. Last, the content was methodically recorded of each article in the following categories: Below explains how each study was classified based on focus, see figure 1.
The data collected from the articles included: year of publication, first author, the purpose of research, approaches taken in research, informal learning environment, and result of research findings. The analysis of this data resulted in several themes that address the two research questions as defined: 1) What mentoring approaches are used in informal K-12 STEM programs? 2) What are the benefits for industry in mentoring K-12 students?

Based on the full-text analysis several common themes emerged about the research questions. The first was, three structures of K-12 mentoring in informal programs, group, individual, and virtual. Next, themes regarding the benefits of mentoring to industry partners emerged which identified internships and co-ops as employment gateways and a method to help increase STEM awareness for K-12 students.

The 39 publications are distributed in the following themes across the two research questions:

**Question 1: What mentoring approaches are used in informal K-12 STEM programs?**
- Group Mentoring. Environments with more than one mentee to mentors, many mentees, and mentors, or more than one mentor to one mentee (n=7)
- Individual Mentoring. Environments with one mentee and one mentor can also be called one-on-one mentoring (n=15)
- Virtual Mentoring. Environments where mentee and mentor relationships are developed electronically. Also called e-mentoring, telementoring, or online mentoring. (n=6)

**Question 2: What are the benefits for industry in mentoring K-12 students?**
- Industry mentoring used as a gateway for internships and cooperatives (n=11)
- Industry mentoring used to promote awareness amongst pre-college students of opportunities in STEM fields (n=14)

In the remaining sections, we will unpack the meaning of each of the resultant themes within the context of the research questions:

1. What mentoring approaches are used in informal K-12 STEM programs?
Theme 1: Group mentoring

Group mentoring provides an opportunity for multiple people to share (as a mentor) or secure (as a mentee) wisdom and experience at the same time and can be facilitated virtually or in person (Huizing, 2012). Group mentoring is usually structured around a topic, is discussion-based, and requires a safe and supportive area for members to express their apprehensions and views (Single & Single, 2005). In these group discussions about life and education, goals have a positive influence on participants’ orientation towards potential outcomes (Hanlon, Simon, O’Grady, Carswell, and Callaman, 2009). With the consistent development of networking resources like LinkedIn, the ease of opportunity has been put in place for the success of group mentoring with little to the limited structure needed (Huizing, 2012). However, even as the ease of group mentoring has increased, extensive research on group mentoring has yet to emerge (Huizing, 2012).

Theme 2: Individual mentoring (also called one-on-one mentoring)

Individual mentoring, the most common form of mentoring, relate to the shared experience between the mentee and the mentor that promotes the growth and development of the mentee (Bozionelos et al., 2016). In some cases, through informal mentoring programs, students can engage in hands-on research experience outside the classroom with industry professionals that can increase the number of students who pursue STEM careers in the future, especially for students not previously exposed to such fields (Tsui, 2007). One-on-one mentoring programs with a cultural focus can be an effective way to help learners “accept and affirm their cultural identity while developing critical perspectives that challenge inequities that schools perpetuate” (Ladson-Billings, 1995, p.269). By emphasizing the balance of challenge and ability through mentoring and by supporting productivity, self-efficacy and self-worth mentors can cultivate a supportive environment that can boost student motivation for the classroom (Schweinle, Meyer, and Turner, 2006).

Theme 3: Virtual mentoring

Virtual mentoring (also called e-mentoring, telementoring, or online mentoring) has gained in popularity due to the increasing need for flexibility of scheduling. According to (Perez and Dorman, 2001 p.122), “telementoring is an electronic version of mentoring, in which an older, more experienced person shares his or her experience and expertise with a younger protégé in a way that helps the protégé achieve a goal or enter the mentor's world.” Through virtual mentoring, the number of potential mentors is infinite and geographic location is not a barrier and gives many working adults a more practical way to participate in informal mentoring (O’Neill and Harris, 2004). The success of this informal mentoring relies heavily on the organizer of such relationship and resources developed as well as the strengths that the mentor brings to the relationship (O’Neill and Harris, 2004). Virtual mentoring allows for exploration in a broad range of STEM issues in an interconnected and personal way (Bennett et al., 2003).

2. What are the benefits for industry in mentoring K-12 students?

Theme 1: Gateway for internships

Industry mentoring can be used as a gateway for internships and cooperative education programs (co-op) as employment entrances and career fast track success. Industry can support pre-college institutions to prepare students for college and/or industry (Kaufman, 2015). Offering internships and co-ops to high school students can give an opportunity for companies to allow disenfranchised students to gain direct industry experience. These opportunities are typically provided outside the academic calendar, and future employment is an incentive for students to participate. Other skills that are gained from internships and co-ops can include vocational training and work experience (Cook, 2005). Beyond industry internships and co-ops, engaging students in hands-on research experience outside the classroom with industry can increase the number of students who pursue STEM careers in
the future (Tsui, 2007). The importance of showing a positive intrinsic value of a profession, identifying an enjoyable job, and choosing a job that gives responsibility to self and community is imperative to pre-college students (DiLisi, McMillin, and Virostek, 2011). Internships and co-ops are usually thought of activities once a student is in higher education. However, programs like Inroads provide internships and co-ops to “develop and place talented underserved youth in business and industry and prepare them for corporate and community leadership” (Inroads, 2016).

**Theme 2: Increased awareness and engagement**

Industry mentoring used as promoting awareness amongst pre-college students of opportunities in STEM fields: Research shows that personal contact with discipline-related professionals, like STEM, is a significant factor for students when determining a career (Demetry et al., 2009). Industry volunteers can use skills learned on the job to educate students. For example, the Georgia Power corporation used Six Sigma tools and methods to help students develop skills by teaching process improvement methods that could be used in STEM fields (Malik, 2014; Sherman and Luton, 2015). Employee volunteering problems like this example can expand the learning experience by introducing industry knowledge directly to students (Flynn, 2006). Students who attend high-quality STEM informal programs outside of school have improved attitudes towards STEM fields and careers, and an increased interest in STEM (Krishnamurthi and Rennie, 2013). Many of the articles related to this theme presented and discussed the importance of having a professional role model involved in the lives of African American students before college. Hill, Pettus, and Hedin (1990) suggest that the absence of professional role models is a critical issue that prevents the employment of young African Americans into these (STEM) fields. Even in students with satisfactory scores in STEM-related subjects, confidence and interest can decline due to lack of encouragement and professional examples (Hrabowski, 2003). Even though there is an increased need for African Americans to obtain a mentor, there is a shortage of minority mentors in STEM fields, especially science and engineering (Tsui, 2007). However, the use of dynamic language to describe the emergency need for STEM growth like the “STEM crisis,” has caused increased focus organizations including governmental agencies in improving access to STEM programs for all precollege programs, especially African American programs. US2020 is a direct partnership with non-governmental organizations (NGO), and corporations focused on STEM products and programs. This strategy seeks to match one million STEM mentors with students from K-16 especially girls, underrepresented minorities, and low-income children to spark interest in STEM careers (Malik, 2014).

**Discussion**

The first question focused on the mentoring approaches used by informal K-12 STEM programs. Overall, three forms of mentoring were found; however, the effectiveness of the three mentioned was reviewed more in-depth in the articles found. Still, depending on the end goal of the mentoring program, additional mentoring programs may need to be evaluated. Two critical factors from the literature based on the first research question have been assessed. First, findings suggest that despite the lack of thorough research studying the effectiveness of mentoring program types, organizations are still using these mentoring approaches in various informal learning environments. The articles found that mentoring can directly benefit the student in career success. However, the articles did not outline an actual guide to successful mentoring relationships.

The second question focused on the benefits for industry in mentoring K-12 students. Employee volunteering provides professional role models as mentors that can be introduced to students at any stage in the education process. These professional role models can show possible career possibilities in STEM. The findings also suggest the type of program can depend on industry, organization, and even the location of the company. Evidence from these studies suggests employee volunteering through mentoring shows direct value to
industry by creating gateways for future employees and awareness of organization and discipline.

**Conclusion**

Because of the method in which academic publications are circulated, industry may not be knowledgeable of these resources that could assist in outreach investment choices. Direct benefits of our research could include distributing the outcomes of the literature review with this critical “external” audience and stakeholder group, industry. Further, the culminating objective is to evaluate the extent to which evaluation is happening and is reported in industry-supported programs. Potential future work may include exploring and documenting potential indicators and evaluation tools and creating a standard for programs and example case studies. With this information, industry-supported informal outreach programs will have a stronger opportunity to develop evidence-based approaches to meeting the need to advance STEM programs that increase diversity in the workforce. While many articles were analyzed during the review process, more studies should be examined. Also, because there has not been extensive and thorough research of the effect industry has on informal pre-college STEM programs, more research should be conducted to examine the impact of industry in these communities.

**References**


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We would like to thank all of our past, present, and future mentors who inspired us to focus on such topic.

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Work in Progress: Engineering students’ changing conceptions of the value of creativity

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Abstract: The technical engineering curriculum at most universities does not provide many opportunities for students to engage in the creative process. Given these limited opportunities to be creative, we hypothesize that engineering students’ perceptions of themselves as creative individuals and their perceived value of creativity may change during their undergraduate careers. A longitudinal, pre/post-survey design was implemented to address the research question: How do engineering students’ creative self-concepts and their perceptions about creativity change during their undergraduate careers? Results show that students’ creative self-concepts did not change from the first-year to the senior year. However, students’ perceived expectations of creativity behaviours in their engineering courses and the perceived personal and professional value of creativity were significantly lower in the senior year. The results of the study suggest that additional opportunities for students to engage in the creative process need to be more fully integrated within the engineering curriculum.

Introduction and Literature Review

Organizations across the world, such as the Engineer of 2020 by the National Academy of Engineering in the United States, emphasize that engineers need to be more than technically proficient, describing the importance of characteristics such as practical ingenuity and creativity (NAE, 2004). In 2017, the European Society for Engineering Education released a position paper describing key engineering skills, which includes the “ability to adapt as [the] working world continually changes on a local and international scale” (SEFI, 2016, p.3). The report follows that “engineering curricula should support this by developing innovative, entrepreneurial and social skills within the engineering graduate. Despite these international pressures, the typical engineering curriculum primarily focuses on acquisition of technical skills, with creativity emphasized only in the fringes of the curriculum, such as in design courses or entrepreneurship programs.

This work-in-progress, longitudinal study broadly explores engineering students’ perceptions of creativity, specifically their perceptions of themselves as creative individuals and their perceived value of creativity, and how these perceptions may change across their engineering undergraduate career.

Creativity in Engineering Education

While rooted in psychology, research on creativity is robust and spans many disciplines including business, science, and engineering. Although the importance of creativity to engineering is often emphasized, creativity has not been well studied within the discipline of engineering education (Zappe, Mena, & Litzinger, 2013). That being said, research is continuing to expand as the number of scholars in engineering education has
One area of emphasis in this research concerns creativity and the nature of the engineering curriculum. For example, in a study surveying engineering undergraduate students, Kazerounian and Foley (2007) found that many engineering students do not feel they have the opportunity to be creative in their engineering courses. These findings resulted in the authors’ conclusion that, “[c]reativity is not valued in contemporary engineering education” (p. 762).

These results are supported by a study conducted by Zappe, Reeves, Mena, and Litzinger (2015). In their cross-sectional study of students’ self-conceptions of creativity, the authors examined differences on measures of creative self-efficacy, creative expectations, and creative identity in first-year versus senior students. Creative expectations, or students’ perceptions of their instructor’s expectations of creative outcomes in courses, was significantly lower for senior students, for both females and males. As the authors noted, “Both males and females in their senior year feel that their instructors have lower expectations for creative behaviours as compared to first-year students” (p. 12). The creative self-efficacy and creative identity variables were more difficult to interpret, as both interacted with gender. Scores on these measures for males were fairly similar between the first and senior years, but were significantly lower for senior female students as compared to first-year female students. The authors provide two potential reasons for these differences – one is that female engineering students may have to “alter their creative identity in accordance with the expectations of the field” (p. 12) or that female students with stronger creative self-concepts may be less likely to persist in engineering. As the authors note, “…[O]ne can hypothesize that students with a strong creative identity who feel they are not given opportunities to engage in creative activities may not persist within engineering” (p.12).

This potential link between creativity and persistence in engineering was studied by Atwood and Pretz (2016). The authors found that students’ creative self-efficacy was not found to significantly predict engineering GPA but was a significant predictor of persistence in engineering. In other words, students’ beliefs in their ability to be creative individuals were not related to their grades, but did predict whether students would stay in engineering. As Atwood and Pretz state,

“…[C]reative performance is not strongly encouraged or rewarded in the curriculum, and therefore is not a factor predicting GPAs of undergraduates in engineering. Our results are consistent with recent findings that most engineering education programs do not deliberately teach or reward creativity” (p. 550).

While gender was not a significant variable in their study, Atwood and Pretz argue that their fairly small sample size and the characteristics of the university (a small liberal arts institution) may have impacted the results.

**Interactionist Model of Creative Behaviour**

In the industrial-organizational psychology discipline, creativity behaviour is often considered within an interactionist model consisting of a “complex person-situation interaction” (Woodman & Schoenfeldt, 1990, p. 284) including the individual’s demographic characteristics (i.e. gender, ethnicity, etc.), knowledge, skills, and abilities (KSAs), and the characteristics of the situation or environment. While much of the research using this interactionist model is embedded within workplace organizations, the concepts can apply to the university and course ecosystem.

The interactionist model posits that whether an individual will engage in creative behaviours depends on personal and situational characteristics. Students who see themselves as being creative individuals (high creative identity) and who have high confidence in their ability to be creative (high creative self-efficacy) may be more likely to engage in creative behaviours. Regarding situational contexts within a course, instructors can either promote or hinder the likelihood of students’ engagement in creative behaviours through course requirements and interactions with students. However, whether students
engage in creative behaviours depends upon their perceptions of the course environment, which can conflict with instructors' perceptions (Kazerounian and Foley, 2007). Therefore, it is students’ perceptions of course expectations and what is required of them that impact the likelihood of creative behaviours. In a course setting, creative expectations refer to the degree to which students’ feel they are expected to produce creative outcomes.

For this study, five constructs related to students’ perceptions were examined, as defined in Table 1. These include two constructs relating to students’ perceptions of themselves as creative individuals (creative identity and creative self-efficacy) and two constructs relating to students’ expectations of the need to be creative in their courses (creative expectations and creative role identity). The final construct relates to the value that students place on creativity both personally and professionally.

Table 1

Constructs Measuring Perceptions of Creativity

<table>
<thead>
<tr>
<th>Construct</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative identity</td>
<td>&quot;Overall importance that a person places on creativity in general as part of his or her self-definition (Jaussi, Randel, &amp; Dionne, 2007, p. 248)&quot;</td>
</tr>
<tr>
<td>Creative self-efficacy</td>
<td>“Belief that one has the ability to produce creative outcomes” (Tierney &amp; Farmer, 2002, p. 1138)</td>
</tr>
<tr>
<td>Creative expectations</td>
<td>“Degree to which employees perceived their supervisor expected them to be creative in their job’’ ((Tierney &amp; Farmer, 2011, p. 282); Adapted to classroom context for this study</td>
</tr>
<tr>
<td>Creative role identity</td>
<td>“Identification with the role of being creative at work and seeing such activity as a central component of who one is” (Tierney &amp; Farmer, 2011, p. 279); Adapted to classroom context for this study</td>
</tr>
<tr>
<td>Perceived value of creativity</td>
<td>“Perceived value of being creative in both personal and professional settings” (Zappe, et. al, 2014, p. 4)</td>
</tr>
</tbody>
</table>

Research Questions

The purpose of this paper is to study changes in students' perceptions relating to creativity as they progress from their first through their senior year in college. The specific research question explored is:

*How do engineering students’ creative self-concepts, creative expectations, and perceptions of creativity as being important to their personal life and professional careers change from the first to the last year of their undergraduate study?*

Methods

Procedures

The study took place at a large research-oriented university in the mid-Atlantic region of the United States. In this longitudinal study, students completed surveys at two points during their academic careers. In the first three weeks of the fall semester, a pre-survey was administered to first-year students who intended to major in engineering. At the university, students are not officially in an engineering major until the end of their second year; before this period of time, they are designated as ENGR students, or those who intend to major in engineering. A total of 2,595 students received the invitation to complete an online survey
using Qualtrics, a commercial survey software tool, 865 students started the survey for a response rate of 33.3%. Of the 865 respondents, 760 students completed the pre-survey in its entirety for a completion rate of 29.3%. As an incentive to participate, ten respondents for each survey were randomly selected to receive a $25 gift certificate. The study was approved by the university’s Institutional Review Board.

Four years after the administration of the pre-survey, the students who completed the pre-survey were asked to complete the post-survey. Students were specifically asked whether they were majoring in engineering, as some may have ultimately decided upon other majors. The post-survey followed similar procedures with administration towards the end of the spring semester of the students’ fourth (and likely senior) year. A total of 257 students started the post survey for a response rate of 29.7%; 226 students completed the post-survey for a completion rate of 26.1%. For this study, data analysis was conducted only for the participants who completed both the pre-survey and the post-survey and those who still reported majoring in engineering (n=159).

**Measures**

The pre- and post-surveys contained five scales relating to creative self-concepts: creative identity, creative self-efficacy, creative expectations, creative role identity, and the perceived value of creativity. Table 2 gives further details about the five scales. Subscale scores were calculated by summing the numeric responses for each individual.

**Table 2**

*Details pertaining to the five creativity scales*

<table>
<thead>
<tr>
<th>Scale name</th>
<th>Source</th>
<th>Number of items</th>
<th>Likert-scale</th>
<th>Scale total min—max</th>
<th>Example Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative identity</td>
<td>Jaussi, Randel &amp; Dionne (2011)</td>
<td>4</td>
<td>(1—5; Strongly disagree – Strongly agree)</td>
<td>4—20</td>
<td>In general, my creativity is an important part of my self-image</td>
</tr>
<tr>
<td>Creative self-efficacy</td>
<td>Tierney &amp; Farmer (2002)</td>
<td>3</td>
<td>(1—6; Strongly disagree – Strongly agree)</td>
<td>3—18</td>
<td>I have confidence in my ability to solve problems creatively.</td>
</tr>
<tr>
<td>Creative expectations</td>
<td>Adapted from Tierney &amp; Farmer (2011)</td>
<td>3</td>
<td>(1—5; Strongly disagree – Strongly agree)</td>
<td>3—15</td>
<td>My instructors would consider me to be creative.</td>
</tr>
<tr>
<td>Creative role identity</td>
<td>Adapted from Tierney &amp; Farmer (2011)</td>
<td>4</td>
<td>(1—5; Strongly disagree – Strongly agree)</td>
<td>4—20</td>
<td>There is an expectation that I do creative work in my classes.</td>
</tr>
<tr>
<td>Perceived value of creativity</td>
<td>Zappe, et al (2014); Zappe, et al. (2015)</td>
<td>4</td>
<td>(1—5; Strongly disagree – Strongly agree)</td>
<td>4—20</td>
<td>Being creative is important to me professionally.</td>
</tr>
</tbody>
</table>
Participants

Respondents’ demographic information (gender, date of birth, ethnicity, citizenship status, etc.), and academic related information (intended major, SAT/ACT scores, institution granting their high school diploma) was collected through university data warehouse sources. Participants included 159 undergraduate engineering students at a large mid-Atlantic research university. Sixty-seven percent (n=109) were male and 31 percent were female (n=50). The sample was mostly white (86.2%), but other ethnicities were reported such as Asian (5.7%), Black/African American (0.6%), Hispanic (1.9%), and Multi-ethnic (2.5%). Five participants did not disclose their ethnicity.

Results

Since not all creativity scales were measured using the same number of Likert-scale points (some were 5- and others 6-point) and not all scales had the same number of questions, the averages of each scale were converted to a scale of 0 to 1 so meaningful comparisons could be made across subscales. That is, each student’s total scale score was standardized, such that a score of 1 meant he or she answered every question in the scale as “Strongly agree.” Conversely, a score of 0 meant he or she answered every question in the scale as “Strongly disagree.” Then, students’ standardized scores were averaged and compared using paired-samples t-tests. Descriptive statistics are provided in Table 3, and Figure 1 displays the standardized averages from both years for each creativity scale.

There were no significant differences between the time periods for creative identity (mean difference = -0.02, \( t_{(158)} = -1.67, p = .09 \)) or creative self-efficacy (mean difference = 0.003, \( t_{(158)} = .30, p = .76 \)). There were statistically significant differences for the remaining variables: creative expectations (mean difference = -0.03, \( t_{(158)} = -2.66, p = .01 \)), value of creativity (mean difference = -0.08, \( t_{(158)} = -6.61, p < .001 \)), and creative role identity (mean difference = -0.08, \( t_{(158)} = -5.85, p < .001 \)).

Table 3
Descriptive statistics (standardized) for each scale (n = 159)

<table>
<thead>
<tr>
<th></th>
<th>Pre-Survey (Fall 2012)</th>
<th>Post-Survey (Spring 2016)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean (SD)</td>
<td>Median</td>
</tr>
<tr>
<td>Creative identity</td>
<td>0.76 (0.17)</td>
<td>0.80</td>
</tr>
<tr>
<td>Creative self-efficacy</td>
<td>0.78 (0.13)</td>
<td>0.78</td>
</tr>
<tr>
<td>Creative expectations</td>
<td>0.70 (0.15)</td>
<td>0.67</td>
</tr>
<tr>
<td>Creative role identity</td>
<td>0.74 (0.14)</td>
<td>0.75</td>
</tr>
<tr>
<td>Perceived value of creativity</td>
<td>0.84 (0.12)</td>
<td>0.80</td>
</tr>
</tbody>
</table>
Figure 1:

Average standardized creativity scale scores at students’ first year and fourth year

<table>
<thead>
<tr>
<th>Scale</th>
<th>First Year</th>
<th>Fourth Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creative Identity</td>
<td>0.76</td>
<td>0.73</td>
</tr>
<tr>
<td>Creative Self-Efficacy</td>
<td>0.78</td>
<td>0.78</td>
</tr>
<tr>
<td>Creative Expectations</td>
<td>0.70</td>
<td>0.66</td>
</tr>
<tr>
<td>Creative Role Identity</td>
<td>0.74</td>
<td>0.66</td>
</tr>
<tr>
<td>Perceived Value of Creativity</td>
<td>0.84</td>
<td>0.76</td>
</tr>
</tbody>
</table>

Note: The X-axis represents the sample standardized average per scale.

Discussion

The preliminary data analysis for this work-in-progress study results in two major conclusions for the overall data set. First, engineering students’ perceptions of themselves as creative individuals, as measured by scales of creative identity and creative-self efficacy, did not significantly change across the four years of study. In other words, students’ perceptions of themselves as creative individuals and their confidence in their abilities to be creative were stable over time. However, students’ perceptions of the expectations relating to their roles as engineering students and how much they value creativity was significantly lower in their senior year of study. Students were less likely to say that their engineering instructors valued creativity and that they felt it less necessary to be creative in their role as engineering students in their senior year as compared to their first year. They also appear to value creativity as less important both professionally and personally. The overall conclusion of the study is that the engineering curriculum does not impact engineering students’ perceptions of themselves, but does impact their expectations relating to the value of creativity for the engineering curriculum and profession.

One strength of this study is its longitudinal design, allowing for an understanding of how creative perceptions change over time while also controlling for potential cohort effects that can bias results of cross-sectional designs.

The study does have some limitations, however. The sample represents just one context: a large research-oriented university in the United States. Students from other institutions may have different experiences in different engineering curricula and potentially more opportunities to engage in the creative process, which would likely impact results of a similar study in a different context. Thus, future research should attempt to replicate this study in other contexts (e.g., universities that are less research-intensive).
This study focused only on students who completed both measures, and many students did not complete the post-survey. Thus, another limitation is the fairly small sample size which resulted from high attrition from the study in the students’ fourth year. Some of these students likely left the College of Engineering for other majors. One of the next steps in the analysis is to determine whether non-respondents persisted in engineering or transferred to another major in any statistically-discernible pattern.

A further limitation is the reliance on students’ self-report data, rather than more direct measures of creative outcomes or behaviours. One final limitation of this study is that the results are based on a quantitative dataset. While the quantitative data shows an interesting pattern, many questions remain. For example, why do students’ perceptions of themselves not change, but their perceived expectations do? These types of questions call for a qualitative approach to explore the reasons for these findings.

Additional analyses currently being conducted will further explore this dataset. One area that will be explored next is how the results differ based on gender. Do the patterns described above differ for females and males? How do the findings compare to Zappe and colleagues’ (2015) cross-sectional study, which found significant interaction effects on creative self-concepts by gender and year of study? An additional area of future exploration will be to compare the pre-survey results of students who left the College of Engineering to those who persisted. These students, despite having left the College, were still asked to complete the survey in their senior year (but many did not). Is this because students who identify as more creative felt stifled by the engineering curriculum? One approach to answering this question is to determine if students who leave the College of Engineering have higher scores on measures of creative self-concepts. These questions will be explored with the intention of a future journal publication.

The results of this study are somewhat disheartening. They suggest that students perceive engineering to be a discipline without strong expectations for creative behaviours, despite organizations such as the Engineer of 2020 recognizing creativity as an important characteristic of engineers (NAE, 2004). The findings support the results of previous studies by Atwood and Pretz (2015), Kazerounian and Foley (2007), and Zappe and colleagues (2015), all of whom have acknowledged that the engineering curriculum is insufficient in providing opportunities for students to be creative.

Many philosophical arguments about the need for creativity within the engineering curriculum have been forwarded. Determining changes that could be made to the curriculum to promote creative behaviour is an area ripe for research and exploration, though some preliminary work has been done (Zappe, Litzinger, & Hunter, 2012; Litzinger, Zappe, Hunter, & Mena, 2015; Daly, Mosjowski & Seifert, 2014). This study helps establish an empirical basis for change in the engineering curriculum with respect to students’ creativity. Faculty development opportunities may also help instructors set expectations and create assignments that require students to engage in the creative process. Although many approaches will be needed to promote creativity, one thing is clear: the engineering curriculum must change to create an environment that can prepare graduates to meet the needs of a changing world.

References


Zappe, S. E., Mena, I., & Litzinger, T. (March 2013). "Creativity is not a purple dragon," OPEN conference, of the National Collegiate Inventors and Innovators Alliance, Washington, D.C.


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Student Reflections on Proficiency with Learning Objectives: Early Semester Actions and Plans

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Abstract: Students do not always engage in self-reflection when assessing their learning. This makes it difficult for students to plan and act to improve their ability to learn. Structured self-reflection was implemented in a first-year engineering course to provide students with an explicit opportunity to assess their learning. This approach was used in combination with a standards-based grading (SBG) strategy so that students could connect their abilities with clear and transparent learning objectives. A qualitative analysis of students’ week 3 and 5 reflections was completed to generate a method (and codebook) for analysing students’ reflections. This analysis revealed a variety of plans, actions, and connections to the course learning objectives self-reported by students. The SBG plus self-reflection structure shows promise as a transparent means of training students to self-regulate their learning.

Introduction

Assessment via grading is a key aspect of higher education that provides institutions with a metric of how well students performed in their courses (Guskey & Pollio, 2012). How this grading is conducted can vary across and within institutions. Some have suggested the use of criterion-referenced grading approaches, in lieu of norm-referenced approaches, to make course learning outcomes transparent (Heywood, 2014; Sadler, 2005). One example, standards-based grading (SBG), fosters alignment between stated course learning objectives and course assessment through intentional transparency, clear expectations, and feedback on performance (Marzano, 2010; Reeves, 2010). Such an approach focuses on developing, rather than selecting, student talent.

Use of such grading approaches requires students to be cognizant of course learning outcomes (LOs) throughout the course. The system becomes inherently effective when students actively engage in self-assessing their performance, while working on assignments, reflecting on their understanding, and planning or acting to improve their learning (Muñoz & Guskey, 2015; Wiggins & McTighe, 1998). Students must process assignment feedback regarding course LOs and plan and act to improve their learning (Atwood, Siniawski, & Carberry, 2014). Unstructured reflection prompts, such as those found in minute papers, can improve students’ engagement with feedback (Diefes-Dux & Cruz Castro, 2018), but does not necessarily lead to a high level of planning and self-assessment of their learning (Diefes-Dux, 2016). An alternative approach to encourage student engagement with their assignment feedback is weekly, structured reflections that explicitly draw students’ attention to their performance on the course LOs and prompts students’ thinking about their actions and plans.

Students who engage in such weekly, structured reflection have been shown to increase their access to assignment feedback (Diefes-Dux & Cruz Castro, 2018, 2019) and self-report greater use of feedback and resources to guide learning (Diefes-Dux, 2018). Similar increases in level of engagement as a result of using reflection have been demonstrated in engineering education studies of ethical reasoning (Kisselburgh, Hess, Zoltowski, Beever, & Brightman, 2016), leadership competencies (Hendricks, Yasuhara, & Taylor, 2016), and
students’ misconceptions about heat and mass transfer (Chenette & Ribera, 2016). There are indicators that a disconnect often occurs for first-year university students likely because they have yet to establish strategies to undertake such reflection in a meaningful way; their focus tends toward general study skills rather than the development of domain-specific knowledge or course-specific skills (Diefes-Dux, 2016). The focus on general study skills and less frequent access to feedback creates a gap between what students are struggling to learn and how students plan to improve their learning with regards to course LOs. The use of self-reflection is one way to bridge the gap. This study explores students’ early semester plans and actions as revealed through purposefully structured weekly reflections within a course using standards-based grading. The primary purpose of this paper is to share a method and codebook for analysing students’ plans and actions as revealed in their reflections.

**Research Questions**

Student responses to weekly structured reflections were examined to address the following research questions:

1) What is the nature of students’ actions and plans, early in the semester, to improve their proficiency with course LOs?

2) To what extent do students’ link their early semester actions and plans to specific LOs?

**Theoretical Framework**

According to Zimmerman (2002), self-regulated learning (SRL) involves cycling through three phases: 1) forethought, 2) performance, and 3) self-reflection. Forethought entails goal setting and planning. Performance involves the use of selected strategies to monitor one’s own learning processes. Self-reflection includes comparing one’s self-observed performance against a standard as well as reacting to the learning experience. These phases can be taught and modelled through instruction (Zimmerman, 2002).

This study focuses on the use of weekly, structured reflections to drive the development of self-regulated learning and the creation of self-regulated learners (Nilson, 2013). Reflection is concerned with thinking about one’s current knowledge or understanding of an issue or problem to fulfill a purpose or achieve an outcome (Dewey, 1933; Kolb, 2015; Moon, 1999; Schön, 1983; Turns, Sattler, Yasuhara, Borgford-Parnell & Atman, 2014; Turns, Shroyer, Lovins & Atman, 2017). It is an “active, persistent, and careful consideration of any belief or supposed form of knowledge in the light of the grounds that support it and the further conclusion to which it tends” (Dewey, 1933, p. 9). Reflection involves thinking about past and present occurrences and thoughtful contemplation of how the past affects current (Schön, 1983) and future actions (Rose, 2013).

Classroom implementation of reflection is typically used to target some aspect of learning. The increased use of student-centered teaching has encouraged greater use of reflection in the classroom (Sepp, Orand, Turns, Thomas, Sattler, & Atman, 2015). This increased use has led to the formation of groups like the Consortium to Promote Reflection in Engineering Education (CPREE), with the ultimate goal to “improve engineering teaching across a wide range of educational settings and for a wide range of student populations by targeting an essential but oft-neglected component for effective learning: reflection” (cpree.uw.edu).

CPREE recognizes that “Reflection and the promotion of reflective techniques are becoming more important in engineering education because of the expanding need for diverse, adaptive, broad-thinking, and nimble engineering experts who can respond to the ever-increasing challenges that society faces” (cpree.uw.edu).

The increased use of reflection requires an understanding of how engineering education stakeholders perceive reflection both within and outside the classroom (Turns et al., 2015). Csavina, Carberry & Nethken (2016, 2017) revealed that engineering faculty, students, and
practitioners defined reflection as primarily an action of looking back; far less participants viewed reflection as a process or an opportunity to impact future actions. Csavina, Carberry, Cunningham and Harding (2017) added that each of these stakeholder groups found value in undergoing reflection, specifically for the purpose of self-improvement, making meaning of past experiences, or simply to provide time and space for contemplation. Personal and professional uses of reflection by these same groups primarily fell into the categories of remembering or monitoring progress, improving, making meaning, and making decisions (Carberry, Harding, Cunningham, Csvina, Ausman, & Lau, 2018).

This understanding of perceived beliefs about reflection provide a foundation to better understand how to effectively embed reflection in an engineering classroom. Turns et al. (2017) suggest that reflections should be anchored in an experience (e.g. course assignments) and be featured as part of that experience (e.g. the intended learning), rather than tacked-on. The reflection should include a lens (e.g., knowledge base) to allow students to interpret or make meaning of the experience. The reflection should not be a concluding action. An action should be determined through the reflection as a means of moving forward. Each act of an effective reflection should also be intentional (i.e. explicit) and dialectical in order to push students to apply different lenses in their efforts to interpret their experience. These features were considered in the design of the overall reflection sequence (Diefes-Dux & Cruz Castro, 2018).

Methodology

Setting and participants

The setting for this study was a large (N=1600) first-year engineering course offered in Spring 2017 at a Midwestern university in the United States. The course met twice a week for 110 minutes per session throughout a 16-week semester. The overall goals were to develop students’ ability to: 1) apply basic (MATLAB) programming concepts to engineering solutions, 2) represent and interpret data in multiple formats, 3) develop, select, modify, and justify mathematical models to solve engineering problems, 4) function effectively in teams, and 5) demonstrate professional engineering habits. All sections followed the same curriculum with common lecture materials, resources, assignments, and exams. The learning management system Blackboard Learn™ was used to facilitate a well-developed SBG system to assess student work on problem sets, exams, and project milestones (Diefes-Dux & Ebrahiminejad, 2018). One section’s (n=70) reflections were examined for this study.

Student work was assessed by the instructional team with rubrics, wherein each item in the rubric was a learning objective (e.g., “create and evaluate x-y plots suitable for technical presentation”). Each learning objective was assessed on a scale of proficient, developing, emerging, insufficient evidence, or no attempt. The level of performance was selected based on the number of pieces of evidence of proficiency the student demonstrated. For the previously mentioned learning objective, the student had to demonstrate a number of skills including, but not limited to, providing a descriptive title and clearly labelling the x- and y-axes with units. Graders provided response-specific written feedback on each rubric item receiving less than a proficient rating. The ratings and written feedback were available to students through Blackboard.

Reflections

Structured reflection prompts, incorporating the three phases of self-regulated learning, occurred typically at the start of the first class each week. The structured reflections were given at designated times such that the students had both received feedback on a problem set or exam in the last few days and had just submitted the next problem set prior to the start of class. Each reflection began with prompts 1, 2, and 3, which asked students what actions they had taken or planned to take based on feedback (Table 1). Reflection prompts 4 through (X-1) asked students to rate their abilities with each recent learning objective. The rating options were: I can do this on my own without referring to resources; I can do this on
my own if I refer to some resources; I need more practice with this; I need someone to help me understand and do this; or I am not sure what this means. Reflection prompt X asked students to propose a course of action to improve their learning. The expected depth of the reflections was intentionally low, meaning minimum expectations were an examination of one’s skills and competencies. Students had the choice to be more descriptive (e.g., encouraging analysis of one’s actions) (Hatton & Smith, 1995), but the overall interventions were not intended to stretch students toward higher level reflection behaviours (e.g., considering alternatives or multiple viewpoints). Thirteen structured reflections were required in Spring 2017, with 10 such reflections including the full set of prompts.

**Table 1. Structured reflection prompts**

<table>
<thead>
<tr>
<th>Reflection Prompts</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. I have gone on Blackboard and reviewed my feedback on PS0X. [If no, skip to Q4]</td>
</tr>
<tr>
<td>2. Based on your feedback, what actions do you still plan to take to improve your abilities? Refer to specific learning objectives and be specific about your planned actions.</td>
</tr>
<tr>
<td>3. Based on your feedback, what actions have you already taken to improve your abilities? Refer to specific learning objectives and be specific about your actions.</td>
</tr>
<tr>
<td>4 - (X-1). [Rate abilities with recent learning objectives]</td>
</tr>
<tr>
<td>X. For those learning objectives that you are not able to do on your own, what do you plan to do to improve your abilities over the next week? Refer to specific learning objectives and be specific about your planned actions.</td>
</tr>
</tbody>
</table>

Students’ reflections from weeks 3 and 5 were analysed in this study. In week 3, students had received feedback on Problem Set (PS) 1 a few days before they submitted PS 2. This reflection was selected for this study because it was the first-time students had an opportunity to react to feedback. In week 5, students had received feedback on PS 3 a few days before they submitted PS 4. This reflection was selected because the learning objectives for PS 4 (i.e., on the topic user-defined functions in MATLAB) were known to be particularly difficult for students (Marbouti, Diefes-Dux, & Madhaven, 2016).

**Data analysis**

A qualitative analysis of student’s responses to the open-ended reflection prompts was completed (Miles, Huberman, & Saldana, 2014; Saldana, 2015). Two coders undertook an iterative process to achieve 100% inter-rater reliability. The first step included coding five reflections together, while creating an initial coding scheme based solely on reflections from week 3. Each coder then individually coded five more reflections using the initial codebook. The two coders then met to discuss inconsistencies, come to consensus, and expand the codebook. The new codebook was then used to code five new reflections together, followed by five more new reflections individually. The review process was repeated - revealing inconsistencies, coming to consensus, and further expanding the codebook. The original 20 reflections plus 10 additional reflections were then recoded/coded using the new agreed upon codebook. All 30 codes from the week 3 reflections were reviewed and discussed by the coding team when discrepancies emerged. The remaining reflections for week 3 were all coded following the coding of 10 reflections from week 5 to ensure no coding variations emerged as students further experienced the course. A similar process was undertaken resulting in further evolutions of the codebook. All reflections from weeks 3 and 5 were coded by the team, and all discrepancies were discussed to ensure agreement. Table 2 lists the final codes.

All codes were color-coded to identify which statements in the overall response was coded with which code. A modifier was used to denote when a specific mentioning of one or more learning objectives was made. The use of underlining and italics was also used to highlight bridge/adjacent learning objective statements between codes.
Table 2: Coding scheme

<table>
<thead>
<tr>
<th>Actions</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ask</td>
<td>Seek or provide help from/to a person either in-person or virtually. These persons include other student(s), teaching assistants, instructors. Also included are office hours and providing help to others</td>
</tr>
<tr>
<td>Check</td>
<td>Check work or changing implementation of habits, such as reading instructions, coding differently, remembering to do something, focus on or spend more time on something. This might be in reference to the most recently submitted assignment or future assignments.</td>
</tr>
<tr>
<td>Create</td>
<td>Create study materials on one's own. Such materials might include study guides (e.g. flashcards, sticky notes, etc.) and test cases or data sets</td>
</tr>
<tr>
<td>Logistics</td>
<td>Actions around submitting work properly (e.g. uploading to Blackboard issue; formatting files correctly)</td>
</tr>
<tr>
<td>Practice</td>
<td>Work or rework problems that are not part of an assignment being submitted for a grade. This includes reworking past assignments, doing extra problems provided on Blackboard, and references to coding or syntax practice.</td>
</tr>
<tr>
<td>Metacognition</td>
<td>Keep own learning in mind or look to improve (e.g., recognition of one's current state of learning or setting a goal state of learning)</td>
</tr>
<tr>
<td>No Action</td>
<td>No actions taken yet</td>
</tr>
<tr>
<td>Review/Read/Research (RRR)</td>
<td>Look back at or look up materials already viewed or created. This included the course online modules, lecture slides, materials posted on Blackboard, previously graded assignments including feedback, exams, web resources (e.g., Google), tool resources (e.g., MATLAB), LO lists, notes</td>
</tr>
<tr>
<td>Study</td>
<td>Study habits including time management, note taking, and memorizing</td>
</tr>
</tbody>
</table>

Findings

Students’ responses to each of the three open-ended reflection prompts garnered a median of two codes with a median length ranging from 132 characters (week 3, actions planned) to 195 characters (week 5, actions planned).

Actions taken based on feedback

Figure 1 shows a breakdown of comments students made concerning the actions that they had taken based on feedback provided on PS 1 and PS 3. The bulk of their responses for each problem set indicated that they had reviewed, read, or did research (RRR) or checked their work on the next problem set or began changing their habits so as not to repeat mistakes (Check). Also, many comments expressed their thinking about their current state of learning or improving their learning (Metacognition). The comments on actions for PS 3 indicated fewer instances of No Action and Logistics issues and more instances of Practice compared to PS 1 and a few instances of self-created test cases or problems (Create).

![Figure 1: Actions appearing in reflections based on feedback on (a) PS 1 and (b) PS 3](image-url)
The greatest difference in actions taken based on feedback resides in the number of Logistics comments for PS 1. The fading away of these comments for PS 3 is not surprising. Some students have difficulties with figuring out how to format and upload assignments early in the semester. This can often be a distraction from course learning objectives and more significant actions to improve their learning.

**Actions planned based on feedback**

Figure 2 shows a breakdown of comments students made in regard to the actions that they planned to take based on feedback provided on PS 1 and PS 3. Like actions already taken, the bulk of their responses for each problem set indicated that they planned to review, read, or do research (RRR) or checked their work on the next problem set or changed their habits so as not to repeat mistakes (Check). In response to PS 1 feedback, there were a large number of comments that indicated planned Practice; this was not as common for PS 3, where instead many more comments expressed thinking about their learning (Metacognition). Comments of No Action and planning around Logistics and the creation of test cases or problems to work (Create) were infrequent for both problem sets.

![Figure 2: Plans appearing in reflections based on feedback on (a) PS 1 and (b) PS 3](image)

The greater number of Practice comments for PS 1 and Metacognition comments for PS 3 may relate to the course content of these problem sets. In PS 1, students are learning basic MATLAB syntax (e.g., math operations and variable naming). Students may have been less inclined to review course materials in favour of working in MATLAB to learn the syntax. More advanced tasks in MATLAB were undertaken by the time students were working on PS 3. As such, students may have felt they needed more review of the concepts before they considered more practice.

**Actions planned based on self-assessment**

Following their self-rating of their abilities with each of the learning objectives associated with PS 2 and 4 (Figure 3), students primarily commented on planning to review, read, or research (RRR) or practicing (Practice), or they wrote comments on their thinking about their learning (Metacognition). They also planned to Ask others questions, which was something they did not typically comment on having done or planned to do in response to feedback. When reflecting on PS 4 LOs, students commented more on planning to check their work. Comments of No Action, Logistics, and Create were either not present or few in number.
Connections to the learning objectives

Table 3 shows the percentage of students’ comments, by action type, that were explicitly linked to learning objectives (LOs). Overall, the number of comments linked to LOs increased from 41-46% in week 3 to 57-67% in week 5. An upward trend in the linking of comments to learning objectives from weeks 3 to 5 held for most action types.

Certain types of actions likely do not lend themselves to being linked to LOs (e.g., No Action, Logistics, and generic Study habits), while an action like creating test cases (Create) is difficult to describe without making a concrete reference to course content. In between are the actions that were popular among the students – RRR, Practice, Check, and Ask. These actions beg for a connection to the learning objectives, so that students can be more focused with their learning; yet many went without a connection to an LO.

Table 3: Percent of comments that reference learning objectives (LOs)

<table>
<thead>
<tr>
<th>Actions</th>
<th>Actions Taken Based on Feedback</th>
<th>Actions Planned Based on PS Feedback</th>
<th>Actions Planned Based on Self-Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Week 3</td>
<td>Week 5</td>
<td>Week 3</td>
</tr>
<tr>
<td>Ask</td>
<td>8</td>
<td>50%</td>
<td>6</td>
</tr>
<tr>
<td>Check</td>
<td>21</td>
<td>62%</td>
<td>21</td>
</tr>
<tr>
<td>Create</td>
<td>0</td>
<td>NA</td>
<td>2</td>
</tr>
<tr>
<td>Logistics</td>
<td>9</td>
<td>0%</td>
<td>1</td>
</tr>
<tr>
<td>Metacog.</td>
<td>20</td>
<td>65%</td>
<td>19</td>
</tr>
<tr>
<td>No Action</td>
<td>8</td>
<td>25%</td>
<td>2</td>
</tr>
<tr>
<td>Practice</td>
<td>10</td>
<td>60%</td>
<td>14</td>
</tr>
<tr>
<td>RRR</td>
<td>36</td>
<td>42%</td>
<td>31</td>
</tr>
<tr>
<td>Study</td>
<td>4</td>
<td>0%</td>
<td>6</td>
</tr>
<tr>
<td>Total</td>
<td>116</td>
<td>46%</td>
<td>102</td>
</tr>
</tbody>
</table>

Recommendations and implications

The analysis of students’ structured reflections during weeks 3 and 5 of an introductory engineering course provides initial insights into the actions students take or plan to take based on feedback and self-assessment. The use of an SBG system provides a criterion-referenced scheme that allows students to reflect on very specific LOs. The combination of SBG and structured reflections makes it transparent to students where they are succeeding and struggling. The overall structure provides a setting for students to self-regulate their own learning of the course LOs, which in turn affords them an opportunity to develop self-regulating skills. Our results begin to show such development in the early weeks of the course.
Future analysis of students' reflections later in the course may provide further insight into students' development of self-regulation skills and may add additional codes to the codebook. An analysis of students’ reflections before and after receiving feedback on a given assignment and its associated LOs might enable a better understanding of self-motivated versus feedback-motivated plans and actions. A case study analysis of differently performing students’ complete reflection histories might provide insights into how actions and plans around LOs change over time. Finally, a closer analysis of reflection comments coded as Metacognition and all codes with reference to LOs might provide insights into the depth of student thinking about their learning. The results of this work can feed into the design of prompts and instruction for improved self-regulated learning.

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Abstract: For every problem, engineers and designers traverse toward a solution. Navigating this process, there are goals, constraints, and design rationale which are known as design intent and revision. The purpose of this study is to generate a substantive grounded theory on middle school student design intent and revision during an engineering design activity. Forty-two middle school students grouped together in teams of two (dyads) were asked to participate in an engineering design activity and asked to solve an open-ended problem using sketch paper, 3d modelling software, and access to a 3d printer. Each participant was asked questions to gauge their understanding and intentions regarding the design. The data were analyzed from a grounded theory methodological perspective including substantive and theoretical coding, field notes, and memo annotations toward a grounded theory of middle school students’ experience of and navigation through design intent and revision within an engineering design activity.

Introduction
Research shows that using engineering with a motivating task where students use digital fabrication has the potential to increase engagement and facilitate mathematics and scientific learning (Berry et al., 2010) and understanding of the engineering design process (Irwin, Oppliger, Pearce, & Anzalone, 2015). A better understanding of how students experience design intent and revision could assist curriculum developers in creating authentic classroom units and activities that promote higher level thinking and critical reasoning regarding design intent and revision, thus increasing the student’s problem formulation and problem-solving ability.

Design Intent
Engineering design is the process by which objectives, constraints, and alternatives are considered to address a problem in an iterative and incremental process (Anderson &
Ansaldi, 1998) that leads to prototypes and models towards a final product solution. For every problem, engineers and designers traverse toward a solution. While navigating this process, there are goals, constraints, and design rationale to consider. Collectively, these considerations are referred to as design intent. Design intent is defined as the reasons behind a design (Ganeshan, Garrett, & Finger, 1994) or an explanation of why a part of an artifact or entire artifact is designed a particular way (Lee & Lai, 1991).

In engineering and design, there are many definitions for design intent. A survey of definitions shows that the definitions do not contrast one another but have common themes. A suggested definition for this context is “application, domain and context dependent knowledge that describes design space, represents design alternatives and process history, justifies design solutions and decisions and determines the characteristics of features and entities and the relationships among them”(Iyer & Mills, 2006). That definition is more compatible with industry and final drawings in 2D and 3D, where design intent is communicated via representations (Fischer, Nakakoji, & Ostwald, 1995) that are digitally generated or manually sketched.

In K-12 education, engineering design has been viewed as a pedagogy, disciplinary practices, and core disciplinary ideas (Purzer Senay, 2017), and curricula and standards have been generated to advance its inclusion and implementation. According to Berry et al. (2010), engineering design is a pedagogical approach in children's engineering.

Design Revision

One goal in our investigation was to observe how students revise their designs. While students will often bounce from idea to idea, they can also marry an idea. Sometimes students will create a primary generator (Darke, 1979; Lawson, Bryan & Dorst, 2009), and abandon it for another primary generator or commit to their original primary generator longer than they should or even permanently. A primary generator is the entrance to a problem, an initial solution concept generated with simple value-laden objective(s), which is generated before conjecture and analysis, and has not been influenced by all the constraints or analyzed (Darke, 1979). When students refuse or fail to abandon a primary generator, they may develop design fixation, indicating students would be less likely to revise.

Viewing the design challenge as a simultaneous problem formation and solution generation to an 'ill-structured'(Simon, 1973), fixed, under-determined, or overdetermined problem, then it becomes an evolving problem-solution pairing (Dorst & Cross, 2001). This tension and balance between problem formation and solution generation evolved from categorization of designers as either problem-focused or solution-focused approaches (Darke, 1979; Lawson, B. R., 1972), and as design models shifted from analysis-synthesis of the 1960s to conjecture-synthesis to generator-conjecture-synthesis models of the late 1970s. Problem-focused designers aim to learn and research as much about the problem before attempting a solution. Solution-focused designers attempt a solution and make revisions based on what is wrong with their solution.

It is yet to be determined whether younger students are problem-focused or solution-focused, and more research needs to investigate how they scope problems (Dorie, Cardella, & Svarovsky, 2014). Students may or may not spend equal time scoping problems as they do brainstorming solutions (Atman et al., 2007; Jonassen, Strobel, & Lee, 2006). If they have not adequately scoped the problem, there may be a necessity for more revisions because the original solutions were too narrow to address the criteria and constraints, or students are aiming for a still blurry target with their solution.

Research Questions

The purpose of this study was to generate a theory of middle school students’ experience with intent and revision within engineering design. The aim of this study was to better understand how middle school students navigate design intent and revision when tasked with
an engineering design activity. The following research questions framed the data analysis for this study:

1. How is design intent characterized during an engineering design activity?
2. How do the participants navigate through design revision?

Methodology

This Classic Grounded Theory (CGT) study aimed to identify an emergent theory of the design intent and revision experience of middle school students during an engineering design activity. Data was collected and analyzed per CGT methods including, coding (substantial and theoretical), field notes, memos, and constant comparison of all data points culminating in theoretical saturation of the overarching research interest thus resulting in the subsequent grounded theory.

Classic Grounded Theory

Grounded theory (GT) is the generation or discovery of a theory from systematically collecting and analyzing the data (Glaser & Strauss, 1967). The researchers of this study sought to generate a theory of how middle school students navigate design intent and revision within an engineering design activity. Thus, grounded theory is the most influential qualitative method of use when researchers aim to generate theory from the data (Chism, Douglas, & Hilson Jr, 2008; Strauss & Corbin, 1997).

Furthermore, grounded theory data analysis focuses more on identifying patterns than describing the data (Griffiths, 2013). Through meaning, action, and interaction the researchers begin to see the fit and relevance within the context of the study (Giske & Artinian, 2007; Glaser, 2014). This allows the researchers to see things as they currently are and not how one could preconceive them to be (Glaser, 2014).

A grounded theory conceptually presents the relationship between social behavior concepts which emerge from the systematically collected and analyzed data (Glaser & Strauss, 1967); (Holton & Walsh, 2016). For this study, the student’s navigation through the design intent and revision experience is the social behavior that is being explored and the grounded theory is a presentation of the relationships between and among the emerged concepts.

Data Analysis

The coding scheme for this study occurred in two phases beginning with substantive coding (1) and ending with theoretical coding (2). Within substantive coding there are two stages: open coding (1a) and selective coding (1b). Open coding is where the researcher looks to the raw data to identify conceptual codes; selective coding is where the researcher looks for the relationship between those open codes to identify relevant core concepts. Theoretical coding is where the researcher looks for the relationship between the core concepts, previously identified in the substantive coding phase, to establish theoretical codes or phases (Glaser & Strauss, 1967; Holton & Walsh, 2016).

The coding of data is a multi-level process that allows the researcher to start defining a theory from the data collected (Charmaz, 2006). Each coding level has a different analytical focus usually beginning with the deconstruction of the data and finishing with a reconstruction of that data, framing core categories and concepts into a substantive theory. As the researcher moves from one coding level to the next, the current level builds upon the previous levels providing clarity regarding emergent categories and themes. A unique characteristic within grounded theory is that the researcher collects and analyzes the data simultaneously (Chism et al., 2008). This highly active coding process requires the researcher to remain open and aware of what emerges from the data while actively coding (Charmaz, 2006).
Research Study Overview

This study examined the design intent and revision of 42 middle school students during a STEM Summer Camp that were tasked with designing a fidget spinner (popular US toy). The three-hour unit included idea generation, sketching, 3D modelling, and finally 3D printing of the spinner (completed the next day). Each student was asked to sketch a primary design and answer the question “What are you currently doing”. Then, pairs met with a partner to brainstorm, made a revised sketch, and answered the question “What did you do”. Finally, students were asked to model the spinner using a 3D software package and print the spinner using a 3D printer.

The study was conducted in four phases as the researchers attempted to generate a theory as to how middle school student’s navigate design intent and revision within an engineering design activity. It is important to note that this study started with the general interest of gaining more knowledge of how design intent and revision are experienced by young problem solvers.

Phase One

Phase one began with the selection of an initial dyad. The researchers then began open coding the transcribed text (answers of questions one and two) of the participant aiming to identify core categories by assigning codes to lines of raw text. During this phase, the constant comparative method of analysis is primarily a comparison between open codes toward identifying relationships among them concerning the primary concern of design intent and revision within an engineering design activity.

Phase Two

Phase two began with selective coding of the open coded transcripts from phase one. During this selective coding process, the researchers used the constant comparative method of analysis to compare the emerging core category and assigned open codes from phase one to begin identifying relatedness among them concerning the primary concern of design intent and revision within an engineering design activity. During this phase, theoretical concepts began to emerge and through theoretical saturation of the assigned selective codes the researchers were guided into phase three. The researchers also annotated memos during this phase capturing the researcher’s conceptual ideas as they occurred.

Phase Three

Phase three began with the researchers reconstructing the pieces of text initially deconstructed in phases one and two by using the constant comparative method of analysis between the previously identified theoretical concepts. During this process the researchers were looking for relatedness or patterns among the selective codes. Through theoretical saturation of these newly formed theoretical codes the researcher stopped the reconstruction of the data and began to generate the grounded theory which then begins phase four. The researchers also annotated memos during this phase capturing the researcher’s conceptual ideas as they occur.

Phase Four

Phase four began with the theoretical sorting of field notes and memo annotations toward identifying patterns or relatedness among them using the constant comparative method of analysis. A substantive grounded theory is generated as a result of the systematic data collection and analysis of the study.

Grounded Theory

This grounded theory is an exposition of middle school students’ identified experience with design intent and revision during an engineering design activity. This theory is grounded in the data and applicable to other populations within similar contexts (Holton & Walsh, 2016).
Since students were asked to type reflections online as they worked on their designs, many of the produced texts have typographical errors. When quoting directly, the researchers corrected these types of errors for the sake of clarity, while retaining the students’ original voice and word choice. Indicators such as Memo#, Participant#, and Field Note# have been removed from this document and presented as (e.g. indicators) for readability and clarity. However, a full manuscript with transcript sections and indicators are available upon request (see first author contact information above).

**Design Intent**

1. **The Summary of First Question’s Memos**

   From the collected data, students' answers for Question 1 show that students consider the durability and safety of their designing fidget spinners which is related to structural perspective and engineering aspect at the same time they have visual consideration of their fidget spinner (e.g. indicators). Students display a desire to design their own original product while they would like to use themes from their life for fidget spinners such as Christmas holiday, or famous cartoon characters (e.g. indicators) While students mention the number of bearings, they need to use for their fidget spinner, they want to be sure their design is strong enough. Students think that there is a relation between the number of bearings and the durability of their fidget spinner (e.g. indicators)

2. **The Summary of First Question’s Field Notes**

   The most salient codes related to the Field Notes of Question 1 are engineering design perspective and design intent. Students show their interest in designing a fidget spinner while they think of how many sides their fidget spinner will have. Students believe that it would affect the spinning of their fidget spinner (e.g. indicators) and durability of design (e.g. indicators). Moreover, they mention where they could get the idea for the themes they would use. They emphasize the originality of their work. Another point, students were considering designing starts from planning, sketching, digitize their sketch in order to print them with 3D printing (e.g. indicators).

3. **The Summary of First Question’s Codes**

   Students' answers for Question 1 reveal their engineering design skills, their design intent, and their revision abilities. Students have indicated their goal, themes, and purposes from the beginning of their design process. Awareness of design steps indicates that they are using the engineering design perspective with holistic overviews. Students express their understanding of the engineering design process by mentioning how they plan to work on sketches which follow prototyping, and printing. Having this design intent is supporting the idea of their revision development to exchange feedback and change their design accordingly.

   (e.g. indicators)”Making fidget spinners come to life by 3d printer you see we first; stretch (sketch) our design then see how many bearings are we gonna put in our figet (fidget) spinner after that stretch (sketch) out design that we gonna make with our design.”

**Design Revision**

1. **The Summary of Second Question’s Memos**

   The salient point related to memos of the second question is a revision of original sketches. Students mainly mention accepting and offering feedback to improve their original sketches. Also, formative and summative evaluation show up unconsciously while students are working with peers (e.g. indicators). For instance, some students make changes by observing others' workings and then, get feedback from peers (e.g. indicators). Besides, many of students state the importance of group working for criticizing the sketches and making brainstorming on them to create better designs (e.g. indicators).

2. **The Summary of Second Question’s Field Notes**
The field notes of the second question mainly focus on three concepts: engineering design, revision, and curiosity. According to the field notes, students are able to use basic engineering skills. For example, students are aware of how long swirls or symmetrical fidgets affect their spinners (e.g. indicators). Also, students revise their sketches in regard to their peer’s comments and the idea of spin well (e.g. indicators). In addition to engineering skills and revision concepts, the field notes show that students also carry a curiosity about the result of 3D printer (e.g. indicators).

3. The Summary of Second Question’s Codes

The eye-catching points of the second question are concepts of revision, social interaction, and satisfaction. Students’ responses in terms of the revision concept indicate accepting and offering feedback in addition to changes in the original sketch (e.g. indicators). Besides, students also mention their social interaction during the group work. They state brainstorming activities that helps them to analyze their designs and give them new design ideas. Also, some students describe their enjoyment while talking about the interaction with their peers (e.g. indicators). Moreover, satisfaction is another concept among responses of the second question. Students talk about their self-satisfaction while describing their work process (e.g. indicators).

Results

Drawing on a grounded theory approach, we analyzed students’ responses at the two points during the fidget spinner activity to address our research question. To recap, our first question was about how students characterized their design intent, and the second asked about how they navigated the design revision phase. While our analysis was grounded in the sense that we allowed themes to emerge from the data, it was also guided by key aspects of each of the core concepts. As we address the student reports of design intent, we organize the emergent themes based on essential elements discussed above: their goals, the problem constraints, and the design rationale. In exploring their experience of the design revision phase, we found themes and patterns emerging that pertained to the evolving nature of the problem-solution pairing, and also about the degree to which students moved through the primary generator-conjecture-analysis sequence as they worked on the project.

Insights of Design Intent

During the first stage of the design task, students reflected on their design intent, encompassing themes about their goals, awareness of task constraints, and the rationale they brought to the design process.

Goals

Students’ reflections often indicated goals that were consistent with what STEM camp instructors had in mind. Many students articulated goals around the performance of the fidget spinner such as the spinner’s durability and safety. For example, one student, in describing the number and location of bearings in his spinner, wrote “[i]t is called an AXLE spinner and it’s really durable” (e.g. indicators). Another explained how the intended design aimed for durability “… around the spinner will be a tiny bit of plastic so it doesn’t fall apart” (e.g. indicators). This same student indicated that safety was a goal: “[the spinner] should not cut me because of how the spikes are set up.” Touching also on the appearance of the fidget spinner, a theme we elaborate on below, one student explained that safety need not be sacrificed for appearance “I used sharp edges... but in a way that it looked cool but didn’t hurt me.” Thus, as expected, students articulated conventional goals for their design of durability and safety.

Students also had the opportunity to enter their fidget spinners in competition, and so a goal of “high performance” in a competitive context was apparent in some of the students’ reflections. Indicating a desire to enter the spinner in the STEM Olympics “I did my design to try and win the contest” (e.g. indicators). Others were already strategizing about the
demands of competition as part of their design intent. “We are thinking of tricks for the
Olympics” (e.g. indicators) noted one student, while another explained “[w]e are making 3D
fidget spinners to enter them in the STEM Olympics. The tricks we’re trying to do are hard” (e.g. indicators).

**Task Constraints**

To a lesser extent, student writing indicated that constraints were embedded in the design
task as posed. Students occasionally indicated an awareness that the availability of materials
could be a constraint on their designs. A few students, for instance, hedged a bit on color:
“[H]opefully it can be a black spinner or a dark color one” (e.g. indicators), or “It is going to be
gold, but if they don’t have gold it will be orange or yellow” (e.g. indicators). This awareness
of possible constraints on the design intent also extended to the structural form: “[M]aybe if
we get any caps I may design the cap to look like the outside of the cockpit” (e.g. indicators). Thus, students showed awareness that full embodiment of their intended design may not be
possible, and often already had a backup plan in mind.

Interestingly, one student saw the testing process itself as a type of constraint, indicating that
the goals for which the testing process was intended to assess did not necessarily coincide
with the student’s goal. The student lamented “I was sad that I would have to drop my fidget
spinner [as part of the test phase], as that ruins it” (e.g. indicators). This suggests that for
some students, it might make sense to ask them to also develop tests that match the design
goals that they have for their product, in place of or in addition to more standard tests of
performance.

**Design Rationale**

Finally, although the writing prompt did not specifically ask for a design rationale, some
students offered aspects of a rationale in describing their design intent work. Several
designers specifically related the number or position of the bearings in their designs with
likely future performance of the spinner, just as the student quoted above attributed the
durability of the AXLE spinner to the number of bearings (e.g. indicators). A second student
offered this rationale: “[T]he 4 bearings will be set up in a square shape so it spins good” (e.g. indicators). In general, though, students did not usually include design rationale
elements in their responses to the prompt. Such rationale discourse demands fairly abstract
thinking in this initial phase, when students have not had a chance to receive feedback or
think together about how well the design would work. Moreover, students may have
interpreted the prompt “what are you doing” as an invitation to describe concrete actions
rather than the thinking and justification behind those actions.

**Evolving Problem-Solution Pairing**

Students reported discussions with partners during the second phase that focused on
problem-formation, solution-generation, as well as a balance of both. When asked to write
about what they were doing in the second phase, quite a few students offered discourse
centered on problem formation. One student reported that their pair started with a discussion
of their desired end product: “[W]e discussed what we wanted our fidget spinners to look like”
(e.g. indicators). Other students reported that their discussions in pairs involved shifts in the
understanding of the problem, such as “[m]y partner told me that I should add extra design.
So I added the spikes and she said that the design looked cool” (e.g. indicators). Notice here
that the interaction within the pair leads to a problem that now includes the visual appeal of
the spinner. Similarly, the problem can be redefined to include other aspects, such as
originality, in addition to visual appeal. “[My partner said] that it didn’t look that good and
everyone else was doing the same thing I was doing so I changed it” (e.g. indicators).

In other cases, the partner talk centered more squarely on solution generation.
Straightforward suggestions were made such as: “[My partner] just said that [it] needs
something to connect the things” (e.g. indicators). Other solution generation talk reported by
the students focused on the collaborative revision process itself: “When me and my partner
met we looked at some designs for fidget spinners, picked designs from ones we liked and added them to ours... we gave each other tips on what to add on, what to take away” (e.g. indicators).

For many pairs, the discourse appeared to be more balanced, including both problem-formation and solution-generating elements. For example, “[My partner said] I should make [the fidget spinner] wider. The reason why is because the bearings would not fit in [in original design]” (e.g. indicators). Suggesting the inclusion of safety as a design consideration, a student noted: “I gave him the idea to make his smaller so he would not cut himself” (e.g. indicators). Another student wrote: “I was told that I should add longer swirls to fill up most of the space... then I added feeling to the swirls and added my initials as well” (e.g. indicators). In this example, a reconsideration of the problem takes place -- the need to fill up most of the space -- with a suggested solution to add longer swirls to the design. This student then built on that revision process to shift the problem again to include visual appeal and self-expression with solution elements “adding feeling to the swirls” and “add[ing] my initials.”

Primary Generator-Conjecture-Analysis Sequence

There was a strong tendency for students to report accepting feedback during the design revision stage. Nearly all students indicated that they accepted suggestions for an improved design from their partners, e.g., “After we shared ideas it made our spinners look more realistic” (e.g. indicators) and “[W]e made changes and decided if they were cool with the other person... if they agreed and they were satisfied then they made the change to their sketch” (e.g. indicators). Students did not always find the results of accepting feedback to be satisfying, however: “They told me how to draw it. I still couldn’t and then I created a new one and it’s worse than the last one. I am just going to make a [simpler] bone spinner now” (e.g. indicators). Nor did they necessarily feel the need for feedback, “I worked alone and I did a better sketch” (e.g. indicators), articulating a degree of self-satisfaction in a solo design revision process. This pattern suggests that for the most part, students were willing to move on from their primary generator, that there was very little design fixation.

Evidence of conjecture and analysis thinking on the part of students was somewhat scant in the reports we analyzed. As can be seen in examples above, the suggestions and revision moves tended to be definitive, lacking a sense of provisional tentativeness. One exception: “When I met with my partner my idea changed. Instead of one pineapple I have two. She told me [to] make sure it is symmetrical so it is not wobbly... hopefully it will work” (e.g. indicators). Here, the conjecture is that having two pineapples instead of one will yield a symmetrical design that in turn will spin well, but it is implied that the conjecture has to be tested to determine if the design will “hopefully” work. Her partner (e.g. indicators) also conjectured that symmetry would help it “spin evenly... [so] when our spinner come out of the 3D printer we will see if our sketches came out as planned." Only one pair seemed to enact multiple rounds of revision of sketches, signaling iterative conjecture/analysis beyond the primary generator: “[W]e looked at each other’s original sketch and make some changes to them... The suggestions we made were helpful. ... Then we drew it and looked to see if we needed any more changes...” (e.g. indicators).

Implications for Engineering Education

The following are the implications for engineering education action following the presentation of the findings of this research study:

1. There was an increase in enthusiasm and engagement once students started working in pairs (group-think). Students showed enhanced ownership of design during the revision process, both while offering revision suggestions and determining which suggestions they should accept for themselves (their design). There was also a correlation between enthusiasm and engagement with a clearly articulated design intent.
2. Group-think and working in dyads could provide enhanced engagement of middle school students during engineering design activities, specifically within the areas of design intent and revision. Also, students could develop a higher critical reasoning disposition by being reviewed and reviewing simultaneously.

3. The writing by students in this STEM summer camp demonstrated strong and robust awareness of the overall process of engineering design, and this seemed evident from the design intention stage. An emergent theme that was clear at both the design intent and revision stages in the degree to which students wished to express a sense of ownership of the process and their work product. This could be applied when designing authentic classroom experiences by curriculum designers.

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Student perceptions on intrapersonal skills required for academic success

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Abstract: Intrapersonal skills include the ability to regulate emotions and accommodate authority, which includes motivation and time management. The purpose of this study is to ascertain student perceptions on what they think is personally required to achieve academic success when considering motivation and time management. A time-lag study (2016-2018) is used to gather quantitative data from 35 mature returning engineering students using an online questionnaire. Results indicate that students would require a study plan at the start of the semester, while also creating a routine time and place to study as part of their time management skills. 80% of the students indicated that their academic success would depend, not on their circumstances, but rather on their own attitude, which speaks to motivation. A potential challenge to academic success would be meeting physiological needs. These perceptions may help identify more appropriate academic student support that is required beyond the disciplinary knowledge of the module.

Introduction

“The mark of higher education isn't the knowledge you accumulate in your head. It's the skills you gain about how to learn” (Brainy Quote, 2019). These words, by an American author Adam Grant, highlight the importance of helping others HOW to learn, instead of just filling their heads with knowledge. In fact, one of the 12 skills, or graduate attributes, listed by the International Engineering Alliance (2013) includes “life-long learning”. Students must be helped to learn throughout their lives, as knowledge turn-over occurs more rapidly than ever before. To accomplish this, requires that students possess specific intrapersonal and interpersonal skills.

Interpersonal skills refer to building relationships while intrapersonal skills include the ability to regulate emotions and accommodate authority (Cowlishaw, Birch, McLennan, & Hayes, 2014). Interpersonal skills relate to communication and collaboration with others while intrapersonal skills relate to metacognition, conscientiousness, and self-direction (Pellegrino & Hilton, 2013).

Major interpersonal skills include the following: verbal communication (what we say and how we say it), non-verbal communication (what we communicate without words), listening (how we interpret both the verbal and non-verbal messages sent by others), negotiation (working with others to find a mutually agreeable outcome), problem solving (working with others to identify, define and solve problems), decision making (exploring and analyzing options to make sound decisions), and assertiveness (communicating our values, ideas, beliefs, opinions, needs and wants) (Spitzberg & Cupach, 2002). Intrapersonal skills include time management, stress management, change management, transforming beliefs, transforming character, creative thinking processes, goal setting and life purpose (Mahmudah, 2016). Due to the large list of variables attached to intrapersonal and interpersonal skills, as mentioned above, this study only considers motivation (linked to change management, goal setting and
purpose) and time management. Another key reason for focusing only on these two intrapersonal skills relates to their impact on education.

Numerous studies have shown that poor time management skills usually results in poor academic achievement (Ellis & Knaus, 1977; Mavole, Okuku, & Ringa, 2017; Wesley, 1994) while motivation plays a significant role for students to complete their higher education studies (Pastushenko, Hruška, & Zendulka, 2018). Time management is considered to be one of the most important characteristics of successful students whether they are participating in an online course or in traditional learning activities (Dragicevic, Cukusic, & Jadric, 2014). Moreover, a lack of motivation (also called amotivation) is one of the most critical factors affecting learning, especially in historically disadvantaged institutions of higher learning (Sikhwari, 2014). This is very applicable to this study that presents the perceptions of mature returning engineering students to the Central University of Technology (CUT) in South Africa, which is classified as a disadvantaged university offering traditional learning activities. These students are seen as being older than 25 years of age, having worked in industry for a number of years.

The purpose of this study is to ascertain the perceptions of mature returning engineering student on what they think is personally required to achieve academic success when considering motivation and time management skills. This may assist an academic to better understand and address unrealistic expectations in this regard. The paper firstly considers the importance of academic student support. The study context and methodology is then given, followed by the results and conclusions.

Academic student support

Academic student support is defined as services provided by a higher education institution that are aimed at the fulfillment of students’ needs directly related to the process of studies (Sajiene & Tamuliene, 2012). It includes services provided by an institutions student support department or center (at CUT it is called The Centre for Innovation in Learning and Teaching - CILT) and by academics in faculty. Academics should provide additional academic support to their students as they are regularly in contact with them, exerting a measure of influence over them. Gomez-Rey et. al (2016) supports this as they highlight the importance of student support by academics and administrative staff alike. Providing student support services enables students, and especially disadvantaged ones, to overcome their lack of information, cultural capital or academic preparedness (Sineke, 2014).

Four types of academic student support have been proposed (Moxley, Najor-Durack, & Dumbrigue, 2013): emotional (stress reduction for new students, welcoming atmosphere, help in forming emotional bonds on campus), informational (student roles, program requirements), instrumental (help solving academic problems, life skills, student advocacy), and identity (need fulfillment, self-efficacy, support groups, acknowledgement of cultural diversity). Helping students to identify required intrapersonal skills, in terms of appropriate time management tools and specific behaviors, that can help them to improve their chances of academic success, falls under the third type of support, namely “instrumental”. It has been argued that, rather than providing direct instruction about predefined strategies or tools, academics should provide support that assists students to self-regulate their own learning effectively (Butler, 1998). In other words, instead of telling students what intrapersonal skills to possess, help them to identify appropriate ones for themselves by giving them a selection of predefined and accepted tools and behaviors.

Accepted tools relate to time management that has been defined as the art of arranging, organizing and scheduling one's time for the purpose of generating more effective work and productivity (Shahidin, Said, Said, & Sazali, 2017). Critical behaviors can be traced to Maslow’s Hierarchy of Needs that covers five levels (Maslow, 1943). Level five is self-actualization (achieving one’s full potential); level four is esteem (feelings of prestige and accomplishment); level three is belonging (being accepted by a group or having a good
support / social network); level two is safety (feeling secure at home, at work, in health etc.); level one is physiological (having food, water, warmth, rest etc.). The lower four levels of the Hierarchy are often referred to as “deficiency needs” that must be satisfied before students become motivated to pursue the highest level of self-actualization (A. J. Swart, 2010a).

The theoretical framework of this study incorporates the self-regulation theory. The first branch of self-regulation theory is concerned with what some term “self-control” in amplifying or dampening behaviors towards achieving goals (Karlesky & Isbister, 2016). The social cognitive theory of Bandura (1986) may also be linked to the self-regulation theory that consists of three sub-processes, namely self-monitoring, self-judgment, and self-reaction. Furthermore, behavioral, cognitive, and other personal factors and environmental events all operate as interacting determinants that influence each other. In this study, the academic responsible for an electronic communication module shared previous research with mature returning students relating to specific intrapersonal skills which are required to improve one’s chances of academic success. Students had to choose their own tools or behaviors (self-judgement and self-reaction) that they would want to amplify, or strengthen during their academic studies, in order to achieve the goal of completing their qualification.

**Study context**

Electronic Communication Systems 4 (EKS4) is an optional offering or module for the Baccalaureus Technologiae (BTech: Engineering: Electrical) qualification in South Africa (Central University of Technology, 2015). Students have to obtain a minimum of 120 credits to successfully complete this qualification, which equates to 1200 notional hours. This is similar to the UK, where the credit system requires 10 hours of learning, being the ‘universal equivalent’ of one credit point, but different for Europe where 20 hours of learning is sometimes equated to one credit point (Wall & Perrin, 2015). Students must complete seven modules (7 modules x 12 credits = 84 credits) for this qualification along with a compulsory capstone module (termed Industrial Projects 4) which has 36 credits attached to it requiring a full year of work (A.J. Swart & Toolo, 2015).

CUT operates on a semester basis of roughly 13 weeks where students attend one classroom session per week (five periods, each of 45 minutes in duration with three periods dedicated to practical work in a laboratory). Mature returning engineering students need to be in possession of a National Diploma (minimum of three years to complete) before they can register for the BTech qualification which can be completed within a full year of study. Many of these students have spent a number of years in Industry, returning to the university to upgrade their current qualification. Many more mature students are doing this in order to gain the skills needed for a promotion or new job, to take classes for personal interest, or to begin a new career path after the loss of a job (Cohen, Brawer, & Kisker, 2014).

The syllabus of EKS4 is primarily aimed at telecommunication based students, as it focuses mainly on digital communication, where parts of the transmission and reception path are discussed. The learning outcomes in these modules incorporate illustrative verbs such as define, describe, sketch, analyze, calculate, design, determine and evaluate. The last five verbs are used extensively in the assessments as it places emphasis on higher cognitive learning which contributes to deep learning and critical thinking (A. J. Swart, 2010b). These modules expose students to a number of new fundamental theoretical principles that they have not encountered before, while providing opportunities for problem-based and design-based learning.

Students are required to complete two theoretical based summative assessments (a set memorandum is used for grading with 50 marks available per assessment) and five practical assessments (a rubric is used for grading where the average mark available per assignment is 22). The first summative assessment contributes 25% to the course grade of the student, while the second summative assessment contributes 40%. The practical assignments make up the remaining 35%. Students must obtain a minimum course grade of 40% to gain entry.
into the final examination. The final grade is calculated using 50% of the course grade and 50% of the final examination grade.

Research methodology

A time-lag study (2016-2018) is used to gather quantitative data from mature returning engineering students using an online questionnaire. Reasons for using close-ended questions in this quantitative study relates to time-efficiency, response rates and precision (Swisher, 1980). Close-ended questions can provide precise answers to specific topics, which in this case relates to time management and motivation. Moreover, some students do not attempt open-ended questions as they often do not know what to say, which produces a lower response rate. Providing them with a predefined set of answers makes it easier for them to respond in a quicker time, relating to time-efficiency. Time-efficiency is also achieved by the researcher, as close-ended questions may ease the analysis of the obtained data. The use of close-ended questions may have limited the strength of the responses, or may be subject to bias. However, it can help both students and academics at the start of a semester to quickly identify appropriate academic student support mechanisms that may contribute to improved academic success. The aim of the academic student support offered in this module is not to explore student perceptions regarding intrapersonal skills, but to help them select the most appropriate tools and behaviours required to improve their chances of academic success.

Questions were formulated from previous research of the author based on a list of eight time management tools (Arthur James Swart, Lombard, & de Jager, 2010) from which students had to select their top four that they think would be required during the semester. Questions were also drawn from Maslow's hierarchy in terms of what students thought would be a challenge in terms of becoming motivated (A. J. Swart, 2010a). Instead of telling students what tools or behaviours they need, the academic responsible for the module shared his previous research with them that is related to intrapersonal skills. Students were then asked to identify and select their own tools and behaviours that could assist them to achieve academic success, which then forms part of academic student support.

Time-lag studies usually ask the same questions (or measure the same behaviours) over time (Twenge, 2014). Five close-ended questions were repeatedly asked to a total of 35 students over a 3-year period at the start of each semester, so as to help them identify important time management tools that they should use during the semester, as well as what basic needs will they need to satisfy in order to become motivated. Students were firstly asked to read a specific journal article (related to motivation and deficiency needs) and a conference paper (related to time management), after which they were required to complete an online self-assessment relating to these publications. The answers to these questions were also reviewed by the academic in order to determine what further appropriate academic student support should be provided to these students. Student demography was also obtained during this self-assessment which did contribute a small percentage to the course grade of the student, as all assessments form part of the course structure. Ethical clearance was not required by the university as the data was drawn from the online self-assessments which formed part of the module.

Results and discussions

Figure 1 shows the home languages (left), age brackets (middle) and gender (right) of the students that registered for EKS4 between 2016 and 2018. This module was offered during the first semester of each calendar year, with the final summative assessment scheduled during the start of June. The dominant home languages were English, Sesotho and Tswana (these 3 languages form part of the 11 official languages of the Republic of South Africa (2017)) which are found in the Free State and North-West provinces of South Africa. These two provinces are served by CUT that has its main campus in Bloemfontein, the provincial
capital of the Free State. The majority of students were older than 25 years of age, with 55% of the students being older than 30 years in 2018 (11 out of 19 students). This provides evidence that the majority of students are mature returning students, having worked for a number of years in Industry. Mature returning students are defined in this paper as students returning to higher education after working full-time in Industry for at least three years after completing a three-year qualification. This view is similar to that of McLennan (2006) who defines a mature student as someone older than 25 years of age studying at tertiary level. Males are the dominant gender, which has been noted in Engineering for many years (World Bank, 2012).

Figure 1: Student demography

Figure 2 highlights the results of student responses to the question on “which forms of behaviour can lead to poor academic achievement?” Recall that these students were first asked to read a journal article and conference paper related to time management and deficiency needs. These publications were produced by the academic responsible for EKS4, and focused on undergraduate African engineering students at a university of technology in South Africa. This was therefore applicable to these mature returning students. The students were asked to rank the options (shown on the x-axis of the figure) according to priority. Poor time management skills took first place, with the absence of deficiency needs being reported as the second highest contributor to poor academic achievement (12 students ranked it in second place). Eleven (11) students ranked stress or anxiety in third place, while 2 ranked it in first place.

Figure 2: Forms of behaviour leading to poor academic achievement
Table 1 and Figure 3 show the results of student responses regarding deficiency needs. Again, students were asked to rank the options according to priority. The dominant deficiency need that should be satisfied was recorded to be a “daily breakfast”, while a “clean residence” took second place. A “secure study area” was listed as the third priority with “regular exercise” in last place. These options were drawn from previous research published by the academic responsible for EKS4 during 2016. Options 1 and 4 (Daily breakfast and Regular exercise) form part of the physiological needs of students, according to Maslow’s Hierarchy of Needs, while options 2 and 3 form part of safety needs. These two needs form the bottom two levels of Maslow’s Hierarchy, often being referred to as “basic needs” that must be satisfied before moving on to the upper two “psychological needs” (being esteem and belonging). Once all four levels have been achieved then self-actualization can occur where one can become motivated to reach one’s full potential.

<table>
<thead>
<tr>
<th>Question</th>
<th>Options</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which deficiency needs of students must be satisfied before students become motivated to study (SELECT TOP 2)?</td>
<td>Daily breakfast</td>
<td>24</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Secure study area</td>
<td>7</td>
<td>2</td>
<td>15</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Clean residence</td>
<td>1</td>
<td>15</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Regular exercise</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>12</td>
</tr>
</tbody>
</table>

It is noteworthy that student responses also highlighted “physiological needs” as their greatest potential challenge to achieving academic success (see Figure 3). This equates well with the options recorded in Table 1 (daily breakfast and regular exercise). Belonging ranked last in terms of priority. Many of these mature returning students have already built a professional relationship with fellow colleagues at their place of employment, and thereby already experience a sense of belonging. However, even if they have their own social networks away from their studies, they may feel isolated from the rest of the student body due to their age (Waller, 2006). It is very encouraging that the majority of the students indicated that their attitude, and not their circumstances, would have the biggest effect on their academic success. Attitude speaks to motivation which is required for students to successfully complete their higher educational studies. Ilgan (2013) found that academic achievements are closely related to student attitudes, while attitude can drive motivation, and motivation can change attitude (Huong, Casadesus, & Marimon, 2017).

Figure 3: Questions relating to academic success

Figure 4 highlights the responses of students with regard to eight specific time management tools. These specific tools were previously published by the academic who was responsible
for EKS4 in 2016. The top 4 tools, ranked by the students in order of priority, include a “study plan and schedule” (blue bar), “maintaining the schedule” (red bar), “a time planner” (grey bar) and “a routine time and place to study” (orange bar).

![Figure 4: Top time management tools selected](image)

### Conclusions

The purpose of this study was to ascertain the perceptions of mature returning engineering students on what they think is personally required to achieve academic success when considering motivation and time management skills. A total of 35 students completed an online self-assessment over a period of 3 years at the start of each semester. The questions to these assessments were drawn from a journal article (relating to motivation and deficiency needs) and a conference paper (relating to time management) which students had to read prior to completing the online self-assessment. This formed part of academic student support where the author shared his previous research relating to motivation and time management.

Student perceptions reveal that not all students are aware of the need to set a study plan at the start of a semester. Academics need to address this concern in class, providing at least two different study plans that may be followed. A concern that academics would struggle to address relates to the physiological needs of the student. Almost all of these students are employed on a full-time basis, having hectic workloads to fulfil. Daily breakfast and regular exercise would be compromised at times. A suggestion would be to remind these part-time students on a weekly basis of the benefits that come from these activities that are classified as basic needs that must be met in order for psychological needs to be met and motivation to occur. 80% of the students indicated that their academic success would depend, not on their circumstances, but rather on their own attitude, which speaks to motivation.

A limitation of this study is the number of students (35) who responded to the online self-assessments. However, CUT is the smallest university of technology in South Africa, and does not draw many students in the field of electronic communication. Another limitation relates to the fact that only quantitative questions were asked. However, the aim of the academic student support offered in the module EKS4 is to help students select appropriate time management tools and become aware of necessary basic needs that they must satisfy in order to improve their chances of academic success.
Obtaining student perceptions regarding which intrapersonal skills are important to possess in higher education may help an academic to get to know his or her students better, thereby helping the academic to provide more appropriate academic student support, if needed. This is perceived as additional assistance and guidance (termed academic student support) that should be offered to all students above and beyond the disciplinary knowledge of the module, that may help students to improve their chances of academic success.

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Patterns of Monthly Student Access to Feedback by Section in a Large Course using Standards-Based Grading and Reflection

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Abstract: Feedback should fuel reflection and reflection should entail critical thinking on an experience and lead to insight and action. For students to engage with their feedback, they must first access it. In a multi-section first-year engineering course, standards based grading (SBG) provided clear and ongoing feedback on students’ attainment of learning objectives, and reflection on ones learning was seen as being a potential means to encourage timely access to that feedback. Course sections’ monthly average access to feedback, as determined from click-stream data gathered as students accessed rubrics within a learning management system, underwent cluster analysis to group feedback access behaviours by course section. Course sections that engaged in structured reflections were found to behave similarly, accessing feedback more frequently throughout the semester, particularly early in the semester. Non-reflection sections showed three distinct behaviour patterns that may be related to instructor grading decisions and time of class.

Introduction

Feedback is touted as “one of the most powerful influences on learning and achievement” (p. 81) to both good and bad ends depending on a variety of factors (Hattie & Timperley, 2007). Giving prompt feedback has long been considered one of the "Seven Principles of Good Practice in Higher Education" (Chickering & Gamson, 1987) and continues to be reinforced along with other best practices such as providing feedback that is goal (criterion) referenced, tangible and transparent, actionable, user-friendly, ongoing, and consistent (Wiggins, 2012).

Over two decades ago, Chickering & Ehrmann (1996) described uses of technology for giving feedback and foreshadowed the potential for technology to facilitate assessment systems. Today, learning management systems (LMS) allow instructors to provide feedback to students between and without physical class meeting times, and these systems can document feedback for performance tracking by both instructors and students. These technological capabilities of LMSs should empower students to access their feedback in a timely manner for the purpose of reflection and improving their learning.

The reality is that instructors question students’ engagement with their feedback (e.g., Badir & O’Neill, 2017), and there is evidence to suggest that instructors’ laments of students’ lack of engagement with their feedback may be warranted. Prior work has shown that first-year engineering students, left to their own ends, do not access their feedback in an LMS with a frequency commensurate with the number of graded assignments (Diefes-Dux & Cruz Castro, 2018).

This lack of access to feedback means that some students are not receiving or processing potentially valuable information about the nature of the gap between their intended and actual learning and how to improve. Therefore, these students are missing significant fodder for forward feeding reflection on one’s learning that could lead to personal development (Quinton & Smallbone, 2010). Reflection itself can be used to improve students’ timely
review of feedback (Diefes-Dux & Cruz Castro, 2019) and as well as their use of other course resources (Diefes-Dux, 2018).

Prior work has focused on the frequency with which students access their feedback when structured reflections are and are not used (Diefes-Dux & Cruz Castro, 2018), where structured reflection refers to the use of specific prompts to draw students' attention to their performance on course learning objectives and help them consider actions and plans to improve their learning. The purpose of this work is to examine whether students in course sections employing structured reflection behave differently than sections that do not use reflection with regards to their feedback access patterns over the course of a semester.

Standards-Based Grading

Standards-based grading (SBG) is a criterion-referenced form of assessment (Guskey, 2001; Heywood, 2014). It uses well-articulated learning objectives as the basis for curriculum development and assessment. The clear articulation of expectations in the form of learning objectives, the alignment of curriculum to those learning objectives, and the rich feedback based on those learning objectives that comprise a SBG system make this form of grading transparent and meaningful for students, instructors, and other stakeholders (e.g., Boud, 2017; Sadler, 2005; Scriffiny, 2008). For an SBG system to be most effective at improving student learning, students must actively access their feedback and engage in self-assessment of their performance with regards to the learning objectives (LOs). Only then can students effectively plan and act to improve their learning.

Research Questions

Two research questions are investigated in this work: (1) Are there distinct patterns of feedback access for sections of a course in which some sections engaged in structured reflection and others did not? (2) How are these patterns of feedback access similar or different? Differences in feedback access behaviour would not only indicate the potential impact (positive or negative) of structured reflection as a whole but when in the semester that impact occurs. These differences, if they exist, could inform the use of reflection. Differences within the reflection and non-reflection sections might also indicate other factors that affect feedback access that could inform other instructional practices to engage students with their feedback.

Theoretical Framework

This work is anchored in the theory of self-regulated learning, which entails cycling through three phases: forethought, performance, and self-reflection (Zimmerman, 2002). Forethought is about goal setting and planning. Performance is about using the strategies selected during the forethought phase to actively monitor one’s learning processes. Self-reflection is about comparing one’s self-observed performance to some standard and reacting to the learning experience. Engaging in these align with qualities of lifelong learning and can be taught through instruction and modelling (Zimmerman, 2002).

Reflection is concerned with self-examination and exploration of an issue, grounded in an experience, yielding meaning and potentially change in perspective (Boyd & Fales, 1983). In other words, reflection is critical thinking about an experience for the purpose of moving one’s learning forward (Quinton & Smallbone, 2010). Dewey’s making meaning of experiences (Dewey, 1933), Schön’s reflection-in-action (Schön, 1983), and Kolb’s experiential learning cycle (Kolb, 2015) provide the theoretical underpinnings of reflection (Turns, Sattler, Yasuhara, Borgford-Parnell, & Atman, 2014; Turns, Shroyer, Lovins, & Atman, 2017).

Mutch (2003) contended that learning from feedback is only effective if classroom time is dedicated to reflection on feedback. In this study, structured reflection prompts used in class incorporated the three phases as described by Zimmerman (2002) and were grounded in the
experiences of engaging in learning through coursework. It was anticipated that course sections that engage in structured reflection would access their feedback more often and earlier in the semester than those sections that used little to no reflection.

Methodology

Setting and participants

This study was set in a required first-year engineering course offered in Spring 2017 at a Midwestern United States university (N=1600). The goals for the 16 week course were centred on developing students’ abilities to: (1) apply basic (MATLAB) programming concepts to the solution of engineering problems, (2) represent and interpret data in multiple formats, (3) develop, select, modify, and justify mathematical models to solve an engineering problem, (4) function effectively as a member of a team, and (5) demonstrate habits of a professional engineer. Course sections of at most 120 students met for 110 minutes twice each week either on Tuesdays and Thursdays (TTh) or Wednesdays and Fridays (WF). TTh class start times were in the morning (i.e., 7:30, 9:30, or 11:30 am) or afternoon (i.e. 1:30 and 3:30 pm); WF sections only met at 9:30 am and 1:30 pm (Table 1).

Table 1: First-year engineering course section descriptions

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<tbody>
<tr>
<td>Structured Reflection</td>
<td>R1</td>
<td>1</td>
<td>C</td>
<td>a</td>
<td>WF AM</td>
</tr>
<tr>
<td></td>
<td>R2</td>
<td>1</td>
<td>A</td>
<td>b</td>
<td>TTh PM</td>
</tr>
<tr>
<td></td>
<td>R3</td>
<td>1</td>
<td>B</td>
<td>a</td>
<td>TTh AM</td>
</tr>
<tr>
<td>No or Minimal Reflection</td>
<td>NR11</td>
<td>1</td>
<td>K</td>
<td>b</td>
<td>WF AM</td>
</tr>
<tr>
<td></td>
<td>NR1</td>
<td>2</td>
<td>D</td>
<td>c</td>
<td>TTh AM</td>
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<tr>
<td></td>
<td>NR3</td>
<td>2</td>
<td>E</td>
<td>d</td>
<td>TTh PM</td>
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<tr>
<td></td>
<td>NR5</td>
<td>2</td>
<td>D</td>
<td>e</td>
<td>TTh AM</td>
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<tr>
<td></td>
<td>NR6</td>
<td>2</td>
<td>F</td>
<td>f</td>
<td>TTh AM</td>
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<tr>
<td></td>
<td>NR7</td>
<td>2</td>
<td>G</td>
<td>g</td>
<td>TTh AM</td>
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<tr>
<td></td>
<td>NR2</td>
<td>3</td>
<td>D</td>
<td>g</td>
<td>TTh PM</td>
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<tr>
<td></td>
<td>NR10</td>
<td>3</td>
<td>J</td>
<td>c</td>
<td>WF AM</td>
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<tr>
<td></td>
<td>NR8</td>
<td>4</td>
<td>H</td>
<td>h</td>
<td>TTh PM</td>
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<tr>
<td></td>
<td>NR9</td>
<td>4</td>
<td>H</td>
<td>h</td>
<td>TTh PM</td>
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<tr>
<td></td>
<td>NR4</td>
<td>4</td>
<td>H</td>
<td>d</td>
<td>WF AM</td>
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</table>

All sections followed the same curriculum with common lecture materials and resources, assignments, and exams. The primary instructional difference between sections was the use of allotted extra credit that amounted to 2% of the total course grade. Three sections used these points to engage students in self-regulation strategies to improve learning. These sections used structured reflection (see Reflection section below).

A well-developed standards-based grading system was used to assess student work on problem sets (weekly homework assignments consisting of typically three computational problems set in an engineering-context), exams, and project milestones (Diefes-Dux & Ebrahiminejad, 2018). Each graded activity was assessed on students’ achievement of a series of relevant learning objectives for which specific evidence of performance was sought. Grading was done through a learning management system, specifically Blackboard Learn™. Feedback (i.e., ratings and written text) on the learning objectives was available to students through Blackboard rubrics and could be accessed via the Blackboard gradebook. Across the entire semester there were 12 problem sets, five exams (three mid-term exams, the first two of which had separate administrations to individuals and teams of students), and five project milestones that were assessed using Blackboard SBG rubrics. For these assignments, LO ratings were done through the Blackboard SBG rubrics. Problem sets and project milestones also received written feedback on each LO. Written feedback on exams
was returned on the exam papers. Each LO assessed in a rubric was rated on a scale of proficient, developing, emerging, insufficient evidence, and no attempt according to the number of pieces of evidence associated with the LO the student successfully demonstrated. For any LO attempted and receiving less than a proficient rating, written problem- and student-specific feedback was provided to indicate the evidence that was missing or incorrect, occasionally with suggestions on how to improve. Written feedback ranged from short phrases to two sentences per LO.

Each section of the course was assigned an instructional team consisting of the lead instructor, a graduate teaching assistant, and five undergraduate teaching assistants. Some lead instructors and graduate teaching assistants were assigned to multiple sections (Table 1). Grading was done primarily by the undergraduate teaching assistants and supervised by the assigned graduate teaching assistant. In Spring 2017, online grader training was launched to improve reliability of the grading (Hicks & Douglas, 2018).

Reflections

Weekly structured reflections were completed in three sections of the course (R1-R3 in Table 1). These reflections occurred typically at the start of the first class each week. Most reflections came at a point in time where students had both two or three days to review feedback on a previously submitted problem set and just submitted the next problem set prior to the start of class. The reflections asked students if they had accessed their feedback via Blackboard (true or false) and what actions they had taken (Zimmerman’s performance, though in retrospect) or planned (Zimmerman’s forethought) to take based on that feedback (free response). These reflections also asked students to rate their abilities with each recent learning objective (Zimmerman’s self-assessment). For instance, students were asked in week 4 to rate their ability with learning objective 04.01 Create a script that adheres to programming standards. The rating options were: I can do this on my own without referring to resources; I can do this on my own if I refer to some resources; I need more practice with this; I need someone to help me understand and do this; or I am not sure what this means. These reflections concluded by asking the students to propose a course of action to improve their learning (Zimmerman’s forethought).

Thirteen structured reflections were done across the 2017 semester. Of these, 10 included the full set of prompts asking students about their access to their feedback, abilities with recent learning objectives, and plan of action. These occurred weekly from weeks 3 to 9 and 11 to 13. An additional three reflections, occurred in weeks 2, 14, and 15. Two of these asked the students to rate their abilities with the learning objectives and to devise a plan of action. The third only asked students to rate their abilities with the learning objectives. The nature of students’ responses to the reflections are described by Diefes-Dux and Carberry (2019a, 2019b).

Data collection

The data for this study were students’ learning analytics, specifically clickstream data recorded as students navigated Blackboard to the rubrics for the problem sets, exams, and project milestones. Rubrics showed the students how they performed on each LO assessed on an assignment and their written feedback on each LO. Data was recorded for each student’s access to the rubrics for the duration of the course. A record of each access consisted of a student’s ID, the timestamp of the access to the rubric to the nearest minute, and a unique session ID which is created each time a student logs on to Blackboard.

Data analysis

Cluster analysis is an unsupervised learning task the objective of which is to identify homogeneous groups of observations. The idea underlying cluster analysis is that the objects included in a cluster are more similar to each other than objects that are in different clusters. Applications of this class of statistical methods is wide ranging, including marketing, healthcare, science, and education. For this study, the aim was to identify groups of course
section behaviours in students’ access to feedback across the semester. A time series cluster analysis approach was used to characterize feedback access behaviour based on the average number of times students in each section accessed their feedback each month of the semester.

There are multiple methods for doing cluster analysis, one of them is hierarchical clustering. In this clustering technique, objects (in this case course sections) included in the clusters are added or removed repeatedly based on a calculated dissimilarity, which is measured as a distance between objects. Dissimilarity distance is a quantity that reflects the weakness of the relationship between objects in the clusters. The hierarchical clustering technique was used in this study to identify the course sections included in each cluster.

When performing a cluster analysis, a decision must be made about the specific dissimilarity measure used and the number of clusters. This decision was made using the R tool called Tsclust by Montero and Vilar (2014). This tool includes a number of different clustering methods as well as different dissimilarity measures. Using Tsclust, a comparison of four dissimilarity measures with different numbers of clusters was performed. The measures compared were: Dynamic Time Warping (DTW), Dynamic Time Warping with L2 norm (DTW2), Global Alignment Kernels (GAK), and Shape-Based Distance (SBD). The selection of the best dissimilarity measure and the number of clusters was based on the maximization of the Silhouette index. The Silhouette index is a measure that quantifies the degree to which (1) the objects belong in each cluster and (2) that the clusters are different from each other. The Silhouette index was chosen over other cluster validity indices to compare the combinations of distance measures and number of clusters due to its demonstrated consistency and success when used with simulated data with known clustering classifications (Arbelaitz, Gurrutxaga, Muguerza, Prez, & Perona, 2013).

The number of clusters tested for each dissimilarity measure were based on visual examination of the first, second, and third levels of the dendrograms (visualizations generated by the clustering analysis) in combination with a search for a maximum Silhouette index. Since the Silhouette index is based on the dissimilarity distance, the visual examination helps to identify the number of clusters that are more likely to maximize the index.

Findings

The Silhouette index values resulting from the test of the various combinations of dissimilarity measures and numbers of clusters are shown in Table 2. The Silhouette Index is used to rank the combinations from best (rank 1) to worst (rank 13) able to create distinct clusters. The maximum Silhouette index value was found for the Global Alignment Kernel (GAK) dissimilarity measure (Cuturi, 2011) with four clusters.

A cluster dendrogram is a way to visualize the hierarchical clustering results. The cluster dendrogram generated by the GAK dissimilarity measure with four clusters is shown in Figure 1. The vertical axis represents the distance or dissimilarity between clusters, while the horizontal axis represents the objects in the clusters. The numbers of clusters at a certain level of a dendrogram is defined by the number of vertical lines that a horizontal line crosses. A new level is encountered when the number of lines crossed changes. For instance, at a GAK distance of about 0.045, the number of clusters changes from 3 to 4 at level 3 in the dendrogram.
Table 2: Cluster analysis

<table>
<thead>
<tr>
<th>Dissimilarity measure</th>
<th>Level</th>
<th>Number of clusters</th>
<th>Silhouette Index</th>
<th>Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTW</td>
<td>1</td>
<td>2</td>
<td>0.379</td>
<td>13</td>
</tr>
<tr>
<td>DTW</td>
<td>1</td>
<td>3</td>
<td>0.421</td>
<td>12</td>
</tr>
<tr>
<td>DTW</td>
<td>2</td>
<td>4</td>
<td>0.483</td>
<td>9</td>
</tr>
<tr>
<td>DTW</td>
<td>3</td>
<td>5</td>
<td>0.463</td>
<td>10</td>
</tr>
<tr>
<td>DTW2</td>
<td>1</td>
<td>2</td>
<td>0.511</td>
<td>7</td>
</tr>
<tr>
<td>DTW2</td>
<td>2</td>
<td>3</td>
<td>0.432</td>
<td>11</td>
</tr>
<tr>
<td>DTW2</td>
<td>3</td>
<td>4</td>
<td>0.504</td>
<td>8</td>
</tr>
<tr>
<td>GAK</td>
<td>1</td>
<td>2</td>
<td>0.692</td>
<td>6</td>
</tr>
<tr>
<td>GAK</td>
<td>2</td>
<td>3</td>
<td>0.749</td>
<td>3</td>
</tr>
<tr>
<td>GAK</td>
<td>3</td>
<td>4</td>
<td>0.846</td>
<td>1</td>
</tr>
<tr>
<td>SBD</td>
<td>1</td>
<td>2</td>
<td>0.772</td>
<td>2</td>
</tr>
<tr>
<td>SBD</td>
<td>2</td>
<td>3</td>
<td>0.743</td>
<td>4</td>
</tr>
<tr>
<td>SBD</td>
<td>3</td>
<td>4</td>
<td>0.701</td>
<td>5</td>
</tr>
</tbody>
</table>

Figure 1: Cluster dendrogram of time series feedback access using GAK with four clusters

To better view the patterns of feedback access of each of the four clusters, the average number of accesses to the rubrics were plotted against month for each section (Figure 2). When looking at the patterns of access, it is important to take into account that a different number of assignments with feedback were returned to the students to view each month. Two assignments were returned in January, six in February, six in March, and eight in April. The only new feedback posted in May were regrades. It is also worth noting that there was a week-long academic break in March; this may account for the dip in the average accesses in that month. This dip is particularly visible in the access behaviours of sections included in cluster 1.
Cluster 1 sections, which contains all of the reflection sections (R1-R3) and one other section (NR11), accessed their feedback on average more often earlier in the semester than the sections in any other cluster. These sections had average monthly accesses near the number of assignments returned with feedback. Cluster 2 students accessed their feedback on average fewer times from January to March than cluster 1 but had similar average accesses to feedback in April. Clusters 3 and 4 behaved similarly to each other at the start of the semester. Both had the lowest average accesses to feedback. However, cluster 3 had a greater average access to feedback than cluster 4 in April.

NR11, upon review, did minute papers in weeks 3, 4, and 5. A minute paper is short in-class writing activity, which in this case asked students to look at their problem set feedback and consider what they believed they had and had not learned, whether the learning-objective based assessment reflected their learning, and what actions they planned to take as a result of their feedback. For these weeks, which occurred in the last week of January and first two weeks of February, students were prompted to go look at their feedback while in class. This would account for the feedback access behaviours early in the semester being similar to the reflection sections. Diefes-Dux and Cruz Castro (2018) found that students in a section that used minute papers with these sorts of prompts accessed their feedback more often over the entire course of the semester than students in a section that were not engaged in any type of reflection. An alternative explanation for the NR11 behaviour could be the actions of the graduate teaching assistant, who also was assigned to a reflection section R2 (Table 1). This assistant might have encouraged greater student feedback access personally or indirectly through the oversight of the grading quality in the assistant’s sections.

Upon review of the use of Blackboard to conduct grading, the three sections led by instructor H (Table 1), which comprise cluster 4 (N4, N8, N9), were found to have not used Blackboard to return feedback on the project milestones. Rather feedback was returned on the paper copies of student work. Feedback being returned on paper likely accounts for the low feedback access in April, when all project milestone feedback was given.

Cluster 2 contains all of the no or minimal reflection sections that met Tuesday/Thursday morning. Time of day a class meets has been found to affect students’ performance (Marbouti, Shafaat, Ulas, & Diefes-Dux, 2018). While many factors may affect students’ performance, including access to feedback, it is worth noting that cluster 3 contains sections that meet at times of day other than Tuesday/Thursday morning and for which there is no
other ready explanation for differences. The one Tuesday/Thursday morning class exception in cluster 2 that met in the afternoon (NR 3) is interesting because instructor E, on further investigation, was piloting CourseMIRROR, a mobile learning technology for reflection. This app prompted students after each class to provide thoughts on what was most interesting and what was most confusing about the class (Menekse, Anwar, & Purzer, 2018). This level of reflection may have been sufficient to elevate the feedback access behaviours over those seen in clusters 3 and 4, though it may be equally likely that the greater student engagement with feedback may be attributed to the instructor and other instructional strategies used in that section.

Other explanations worth considering regarding difference in feedback access between all clusters, but particularly clusters 2, 3, and 4, might be grading quality and timeliness of the return of feedback. While the graders received training with each problem set and project milestone, the training program was new in Spring 2017 and completion of and engagement in training was not the same for all graders in all sections. Low quality grading may have reduced students’ inclination to access their feedback. In addition, while there was a strict grading schedule imposed on the graders, if a section was even occasionally late in returning feedback, students may have been less likely to attend to their feedback.

Recommendations and implications

Chickering and Gamson (1987) advised that timely feedback and reflection be provided to students when they wrote:

“Knowing what you know and don’t know focuses your learning. In getting started, students need help in assessing their existing knowledge and competence. Then, in classes, students need frequent opportunities to perform and receive feedback on their performance. At various points during college, and at its end, students need chances to reflect on what they have learned, what they still need to know, and how they might assess themselves.” (p. 4)

In this study, first-year engineering students received ongoing feedback on their performance and that feedback was tightly aligned to the course learning objectives. Students enrolled in sections doing structured reflections were provided with opportunities to process and act on their learning.

What is evident from the results presented here is that structured reflections resulted in greater access to feedback and that greater access began early in the semester. This reflection type, and the early semester minute papers, seem to have yielded similar results and seem to overcome other factors that might impede students’ access to feedback, like course time of day. The feedback access behaviours of the sections engaged in reflection in class reinforce Mutch’s (2003) contention that time spent in class on reflection is well worth it. While access to feedback may not always translate to critical thinking on one’s learning and appropriate actions, it is a step in the process.

Future research may investigate clustering based on weekly access to feedback to get a more nuanced look at the sections’ access behaviour and whether different styles of reflection impact weekly behaviour. Further, correlations between these clusters and students’ responses to the Engagement with SBG System Questionnaire, which is an instrument designed to measure students’ engagement with various aspects of an SBG system (Diefes-Dux & Cruz Castro, 2019), could be investigated to find viable alternatives to using click-stream data to measure the impact of different reflection strategies.
References


Acknowledgments

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Influence of personal epistemology on research method: implications for research education

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Abstract: In this paper, the author reflects on six years (2013 to 2018) of teaching research methodology to a cohort of engineering graduate students. An initial study undertaken in 2015 revealed that the students’ personal epistemologies hindered the adoption of appropriate research methods, which undermined the epistemic contribution of their work. The pedagogical challenge was to encourage a level of ontological self-reflection, within which the students could be made aware of limitations of positivism in the analysis of management problems. A number of changes were made to the teaching method, including the use of an awareness questionnaire and more time for class discussion, which collectively resulted in evident improvements to the quality of their research proposals. The result suggests that personal epistemology is a dynamic paradigm which can be influenced, and more importantly, can be disentangled from a student’s decision on what research method to follow for a particular set of research questions.

Keywords
Personal epistemology; research methodology; self-reflection; engineering education

Introduction and Context
Teaching and research are the two principal functions of a public research university. Teaching of research (practice), in the form of an introductory course to research methodology, is thus a vital task, however specious or trite this claim may appear. Whether or not university departments acknowledge the importance of such a course depends on the discipline and the nature of the research undertaken, but generally it is accepted that research methodology should be compulsory for all research students, in order to guide them and provide the necessary framework for them to conceptualise, plan and subsequently undertake their projects.

To prepare and present such a course is a challenge given that there are diverse views on the best approach to ensure the necessary rigour without inhibiting a student’s creative and highly personal inputs to the research process. Structure vs. spontaneity is not the only dichotomy that prevails in this field. Methodology forces theoreticians and philosophers to consider a number of ontological and epistemological difficulties, particularly the extent to which context influences the standard components of knowledge production, including what questions are asked, how these questions are answered and how the data is interpreted.

In this paper, the author reflects on six years (2013 to 2018) of teaching research methodology to a cohort of postgraduate students registered for part-time Masters programmes in either technology management, project management or engineering management (altogether about 150 students per year). The course was presented over two and a half days (20 hours) in March or August. Apart from the examination, usually held in May, the students were required to complete two assignments, the first covering the
development of the research proposal and the second covering a critical analysis of five articles from the engineering and technology management literature. The cohort consisted mainly of engineering graduates who, for the first time, encountered social science subjects that required skills in literacy, discourse, the development of qualitative arguments and the importance of context, rather than numeracy. In this regard, the students represented an ideal cohort with whom to understand the nature of paradigms and how these ontological fixtures could be changed, if at all.

An initial study, conducted in 2016, indicated that the choice of research method had been heavily influenced by a student’s personal epistemology (PE), as opposed to the dictates of the research questions (Singh & Walwyn, 2017). The study used an explanatory sequential method, with the initial step being an analysis of secondary data to determine the dominant research approaches of completed Masters of Engineering Management mini-dissertations (altogether 72 documents) over the period 2013 to 2015 at the Graduate School of Technology Management of the University of Pretoria. In the second phase, a purposive sample of students were interviewed and the transcripts assessed using interpretative phenomenological analysis (IPA), which was particularly appropriate to the objective of developing a more detailed understanding of how students attach meaning to abstract concepts such as epistemology, and how their PE then impacts on methodological choices.

The study found that empirical-analytical (positivist) approaches accounted for 72% of all studies within the research cohort, indicating a strong preference for such an approach. Furthermore, the interviews revealed that the students tended to overlook the methodological considerations, focussing only on research design. There was a general lack of self-reflection and awareness of PE, despite the latter being an important influence over the type and topic of the research, its purpose, design, analytical techniques and even the interpretation of the results. The rather superficial approach of the cohort indicated that the research methods were significantly biased by PE and ill-suited to the research problems, suggesting that a new pedagogical approach should be urgently implemented.

The new approach was implemented in 2017 and then evaluated at the end of 2018; details of the changes to the teaching of the module are listed in the methods section.

Research Questions

The main objective of the project was to establish whether changes in the course content and pedagogical approach had led to greater awareness of PE (and its influence on the choice of research method), and as a result, an improved quality in the research proposals had developed following the contact period, particularly in terms of the discussion on research method.

Theoretical Framework

Epistemology and PE are central to this paper, and a brief explanation of their meaning is therefore justified. The former is broadly the study of knowledge and covers such questions as the nature of knowledge, its justification, its limits, the differences between knowledge and belief, and the diversity of knowledge types (Hofer & Bendixen, 2012). PE, on the other hand, refers to the how individuals understand, justify or evaluate knowledge, and how personal belief impacts on their cognitive processes of thinking, reasoning and learning (Carter & Little, 2007; Hofer, 2000; Hofer & Pintrich, 2004). In educational psychology, it has been usefully shown that PE influences both the nature of teaching and educational outcomes (Hofer, 2001; Montfort, Brown, & Shinew, 2014). PE is a psychological construct that is dynamic in time, and is changed as a consequence of education and exposure to a more pluralistic or relativistic ontological perspective (Hofer & Pintrich, 1997; Perry, 1970).

Saunders, Lewis, and Thornhill (2016) provide a useful summary and illustration of the relationship between the concepts of ontology, epistemology, methodology and method (see...
Figure 1). These terms, and their components, are used inconsistently in the literature; for instance, the distinction between methodology and method is often either ignored or confused. In this paper; the former refers to the systematic and theoretical analysis and justification of actual research methods, whereas the latter covers the specific processes, tools and techniques which are used to undertake the research. Method covers the research action (that which is done), and methodology justifies the method.

Ontological paradigms include realism, critical realism, relativism and nominalism, whereas epistemological perspectives may be described as positivist, post-positivist, constructivist or post-modernist. Unfortunately, many of these terms are used ambiguously and it is often unclear as to whether they refer to an epistemological or ontological construct. In this research, the term ‘research philosophy’, referring to the dominant streams or paradigms, is adopted as a means of clarifying this ambiguity. The four dominant philosophies are shown in Table 1 (Saunders et al., 2016). For instance, a researcher with a world view that aligns with nominalism is more likely to have a constructivist PE and apply a qualitative research method.

These links are not necessarily causal; researchers with a positivist PE may also be capable of following a qualitative approach should this be better suited to the research questions. Furthermore, these philosophies are not static; indeed, previous work on undergraduate engineering students has shown how students might change their paradigms as a consequence of education and context (Perry, 1970; Wise, Lee, Litzinger, Marra, & Palmer, 2004).

Table 1. Examples of research philosophies

<table>
<thead>
<tr>
<th>Research Philosophy</th>
<th>Ontology</th>
<th>Personal Epistemology</th>
<th>Preferred Research Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Realism</td>
<td>Strong Positivist/Positivist</td>
<td>Quantitative</td>
</tr>
<tr>
<td>B</td>
<td>Critical Realism</td>
<td>Interpretivist</td>
<td>Mixed Methods</td>
</tr>
<tr>
<td>C</td>
<td>Relativism</td>
<td>Constructivist</td>
<td>Mixed Methods</td>
</tr>
<tr>
<td>D</td>
<td>Postmodernism/Nominalism</td>
<td>Strong Constructivist</td>
<td>Qualitative</td>
</tr>
</tbody>
</table>
In practice, it was found by the author that a further simplification of the research philosophies was necessary as a means of achieving wider comprehension of the main concepts. As a result, the standard bifurcation of positivism vs. constructivism, as shown in Table 2, was presented to the students. The author is aware of previous work which has highlighted the limitations and indeed the dangers of this simplification (Onwuegbuzie & Leech, 2005). The weakness of the bifurcation in portraying the full spectrum of PEs, was therefore emphasised in the lectures.

Table 2. The standard epistemological bifurcation; positivism and constructivism

<table>
<thead>
<tr>
<th>Positivist</th>
<th>Constructivist</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reality is single, objective and apart from the observer (realist)</td>
<td>Reality is subjective and multiple (relativist)</td>
</tr>
<tr>
<td>Quantitative data derived from experiment</td>
<td>Qualitative data derived from observation</td>
</tr>
<tr>
<td>Reliability is most important (repeatable results)</td>
<td>Validity is important (improved by triangulation)</td>
</tr>
<tr>
<td>Deductive</td>
<td>Inductive</td>
</tr>
<tr>
<td>Location is artificial; all variables held constant except the independent variable</td>
<td>Location is natural; not possible to control any variables</td>
</tr>
<tr>
<td>Mainly experimental, preferably with control</td>
<td>Type of research includes ethnographic, participant observation, case studies</td>
</tr>
</tbody>
</table>

Method

This project was undertaken as a longitudinal study in which the effect of the new pedagogical techniques, introduced simultaneously, was evaluated using data from pre- and post-intervention. Changes to the curriculum included the introduction of an evaluation matrix called the Heightened Awareness of Research Philosophy (HARP) (Saunders et al., 2016 p153), completed before the start of lectures; a broader selection of on-line material and teaching methods, such as videos and class examples; clearer definitions of the different research philosophies, and, in particular the use of bifurcations to assist the students with their understanding of novel, abstract concepts such as ontology, epistemology and axiology; a focus on the difference between knowledge and belief; a class test on the philosophical aspects of the introductory material with time set aside for discussion of the questions and the results; and more emphasis on mixed methods as a relevant and appropriate research approach.

The HARP questions were adapted from the original version (Saunders et al., 2016) in order to ensure local relevance. The questionnaire was then converted to an Excel template, which was completed individually by the students and submitted through an on-line survey, together with other information, such as preferred choice of film genre, religious perspective and sector of work. The latter questions did not form part of this study; they simply provided a suitable means through which to demonstrate statistical analysis with ordinal variables.

In the use of HARP, no assumptions were made about the measurability of PE, or whether measurements using psychometric questionnaires are reliable or valid, even though such claims have been made in prior studies (Carberry, Ohland, & Swan, 2010; Wheeler, 2007). Indeed, the author's experience supports a view that although PE may be 'scored', the metric is not repeatable or reliable since it was observed that students changed their ontological perspectives as a function of context. In this regard, PE is a parameter which should be assessed in an interpretive sense only; HARP was introduced not as a way of measuring PE, but in order to raise self-awareness of the concept and encourage a level of self-critical
reflection on how PE can affect research processes and outcomes. For this application, it is considered to be a valuable tool.

Considering that this study attempted to prompt student self-reflection on their normative framework, there was also the question of whether the choice of method was itself a reflection of the author’s own PE, whose perspective aligns more closely with critical realism than other paradigms. In the first study of the students’ choice of methodology, the same question was simultaneously tackled by two different researchers. Perhaps not surprisingly, the researchers adopted completely different research designs; the one opted for a qualitative study with IPA (Singh & Walwyn, 2017), the other chose a quantitative approach in which students were profiled using a psychometric test, the results of which were analysed using linear regression to determine whether a correlation existed between the profile and their choice of research method (results not yet published).

The quantitative study was inconclusive in its outcome and provided little insight into the main research question. This experience influenced the author (of this paper) to avoid any analogous approach, particularly the use of psychometrics as a means of measuring changes in the students’ PE. Instead, the study used content analysis of the research proposals to infer the consequence of changes to the teaching approach.

Findings

Interestingly, the HARP questionnaire revealed that once the notion of PE had been introduced, students became more self-reflective and more diverse in their epistemological perspectives. In the initial study, it was apparent that the students had either not thought about such questions or were adamantly positivist in their philosophies (Singh & Walwyn, 2017). The HARP results, from this work, indicated a broader diversity of perspectives, as shown in Figure 2, with more balance between the two dominant PEs of positivism and constructivism.

The main result of the research was the positive impact of the changes on the students’ comprehension of research method, as revealed in the quality of the proposals submitted as an assignment for the course (see Figure 3). Prior to 2015, the section on research method in the proposals was either ignored or completed using a ‘cut and paste’ from the proposal template. The actual quote used repeatedly, and labelled as ‘not specified’ in Figure 3 stated that the approach would consist of a “comprehensive literature review with substantiated field research and interviews, minutes of meetings, workshops, etc.” Despite efforts of the author to instruct them otherwise, the students clearly had little understanding of the meaning of research method, and no language with which to describe it. Following the course changes, as outlined earlier, the proposals were more specific about the research method, adopted a

![Figure 2. Profile of students’ research philosophies](image-url)
wider range of approaches, and provided a stronger rationale for their choice of method as a consequence of the type of study and the nature of the research questions.

Figure 3. Profile of research methods; 2013 vs. 2018

The failure of the initial teaching approach should have been no surprise; even the most diligent student struggled to survive two and a half days of continuous lecturing without an opportunity for engaging in other forms of learning. The question was not whether to change, but how to change the approach. The choice of new methods was guided by pre-determined structure of the contact period, and the need to make maximum use of this time. The resultant methods followed a diverse strategy, with the changes including additional content in the lectures on mixed methods, a class test, video material dealing with qualitative research methods, introduction of the self-reflection tool and more time for class discussion based on predefined examples, as already specified.

These changes together contributed to a noticeable improvement in the research proposals. It is stressed, however, that this study was undertaken retrospectively; at no stage was it designed as a research project with a set of clearly defined variables and the usual protocol of a longitudinal study. With hindsight, it would have been more useful as a study in engineering education if the design of the interventions had been pre-considered and structured as a formal research project into the relationship between awareness of PE and research outcome. Based on the routine feedback in the course assessments, the students felt that the revised module was easier to understand and offered them more value. There was also less criticism of the content in terms of its relevance to their research projects. Similarly, the work of student researchers has improved over the 6-year period, even beyond the preparation of their proposals, stretching to the actual process of undertaking the research and then writing the research report.

Conclusions

PE, posited as a psychological construct which influences education and learning, has become an important consideration in understanding how epistemic conceptions respond to tertiary education, and how this can influence educational achievement (Hofer & Bendixen, 2012). In this cohort of postgraduate engineers, a previous study had shown that PE inappropriately influenced the choice of research method, thereby diminishing the epistemic contribution of the work, and intimating that a new approach to the teaching of the material on research philosophy should be followed.

As a result, both teaching method and module content were changed to build more directly an understanding and self-awareness of PE. In particular, the lectures adopted a more structured approach to the core concepts of ontology, epistemology and methodology, whilst constantly reminding the students that this depiction was a simplification of a broad spectrum of paradigms. In addition, the students were required to complete and discuss a questionnaire adapted from their reference material, which was intended to assist in the
overall process of understanding their normative frameworks with respect to the nature of reality and the validity of various types of research.

The study showed that it was possible to disentangle PE and research method. In the context of the methodology course and with the use of these specific tools, students were relatively flexible in their perspectives on important ontological and epistemological questions. This result is encouraging for the teaching of research methodology, given the centrality of the topic to the broader objectives and mandate of public research universities.

**Recommendations and Implications**

The findings from this research will be useful in the teaching of methodology across all disciplines, including engineering. Ontology and epistemology are generally presented as abstract concepts which are not personalised, but coded into separate and rather obscure categories. The personalisation of these terms allows students to attach their own meaning in a self-reflective and constructive process, and engage more deeply in conversations about their conception of reality and knowledge.

Apart from encouraging students to be self-aware, self-critical and self-reflective, the results support earlier studies which recommended further research on the link between pedagogy and PE, and approaches in engineering education research and PE (Douglas, Koro-Ljungberg, & Borrego, 2010; Montfort et al., 2014). Identity is fundamental to PE, and it is therefore not surprising that engineering teaching staff adopt broadly similar or even stereotypical approaches to engineering education (Douglas et al., 2010). Although not covered in this research, the results suggest that both staff and students would benefit from such conversations.

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Through HER Lens: Examining the formation of counter-spaces for Black women in an engineering education doctoral program

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Abstract: Black women are underrepresented throughout the professoriate pathway in engineering education; however, little work has investigated how Black women navigate their pathway to a career in academia as first-generation doctoral students. This qualitative study describes how a group of Black women in an engineering education doctoral program create and leverage counter-spaces to increase academic and professional success. We used a collaborative inquiry approach to investigate how Black women create a community of practice to support themselves while navigating through an engineering education doctoral program. In this work-in-progress paper, our preliminary analysis resulted in two main cultural themes: personal encouragement and academic support. Within those two major areas, several sub-themes were identified such as vulnerability, academic progression, and spatial navigation. By understanding the importance of such cultural spaces, universities can recognize the necessity of such areas outside of doctoral programs to help elevate underrepresented students.

Introduction

Understanding the experiences of Black (descendants of the African diaspora) women is a transnational concern due to the decline in the percentage of Black women who hold bachelor’s degrees in computer science, mathematics, and statistics, and engineering (NSF, 2017; Ross, Capobianco, & Godwin, 2017). In 2017, a report titled “Ignored Potential” discussed the challenges Black women face as they navigate throughout engineering, in addition to various strategies to increase the participation of Black women among various spaces that may impact the trajectory of a Black woman. Fletcher and her colleagues (2017) discussed the systemic factors that impact students’ ability to form strong engineering identities such as role models, feelings of belongingness, and stereotype threat (Fletcher et al., 2017). However, since there is a lack of Black women in engineering, it is “rare” for students to identify a role model in engineering (Tsui, 2007). In this paper, we highlight the need to intentionally study the experiences of Black women in engineering to 1) acknowledge the diversity of experiences of Black women, 2) recognize their value to STEM, and 3) enhance the “upward trajectories” of Black women in higher education.

Women’s involvement in doctoral programs is an understudied area and Black women’s involvement in doctoral programs has received even less attention. Understanding the
absence and underrepresentation of Black women in engineering doctoral programs is a crucial motivation for this research. Current research in higher education suggests strategies like female-friendly environments, to encourage the persistence of women in engineering (Meiksins et al., 2016; Cadaret, Hartung, Subich, & Weigold, 2017; Hunt, 2016). However, the experiences of all women are assumed to be universal and monolithic, and this monolith often overshadows the experiences of those represented in small numbers in engineering, like Black women (Slaton & Pawley, 2015). Although there are resources to support doctoral students, in some cases, Black women experience feelings of marginalization, inconsistent support, or other discriminatory behaviors or practices (both implicit and explicit) where Black women require additional outlets to be authentic, vulnerable and supported during their doctoral journey (Blockett, Felder, Parrish, & Collier, 2016).

 Importance of Counterspaces for Minoritized Groups

Counterspaces are defined by Solórzano and his colleagues (Solórzano & Villalpando, 1998; Solórzano, Ceja, & Yosso, 2000) as academic and social spaces that serve as safe havens for students of underrepresented groups. Solórzano et al. (2000) found that these spaces were created in response to racial indignities endured by Black students. These safe spaces allow students to nurture their learning in a supporting atmosphere where their experiences are validated and seen as vital, challenge negative views of people of color and marginalized groups and create and preserve an encouraging racial climate at their academic institution (Solórzano, Ceja, & Yosso, 2000; Ong, Smith, & Ko, 2018).

Counterspaces can be formal or informal (Carter, 2007) and have been initially described as homogenous, being made up of the same gender or race/ethnicity (Carter, 2007; Nuñez, 2011; Solórzano, Ceja, & Yosso, 2000). Solórzano, Ceja, & Yosso (2000) found that counterspaces “were created within Black student organizations, organizations or offices that provide services to Black and other students, Black fraternities and sororities, peer groups, and Black student-organized academic study halls” (p. 70). Similarly, counterspaces have been described as found “in the margins” of academic programs, meaning outside of central academic spaces such as classrooms or laboratories (Ong, Smith, & Ko, 2018).

Ong, Smith, & Ko (2018) expanded and deepened the definition of counterspaces after their investigation of women of color in STEM higher education. Ong, Smith, & Ko (2018) interviewed 39 women of color in STEM disciplines (e.g., physics, astronomy, computer science, and engineering) at varying career stages (e.g., undergraduate, graduate, and professionals). They were asked to describe their STEM higher education experiences retrospectively. The researchers’ findings allowed them to expand the current notion of counterspaces to mixed racial or ethnic groups and other social arrangements versus homogenous groups. Counterspaces “could be physical settings, such as conferences, or could be conceptual and ideological, such as in mentoring and peer-to-peer relationships” (p. 219). Counterspaces were also found in central spaces, such as STEM departments, rather than in the margins. While counterspaces can occur in various settings, Ong, Smith, & Ko (2018) found five types of counterspaces that participants acknowledged as supportive: peer-to-peer relationships; mentoring relationships; national STEM diversity conferences; STEM and non-STEM campus student groups; and, STEM departments as counterspaces.

Various issues necessitate counter-spaces for Black women and other underrepresented or marginalized groups. The literature steadily demonstrates how Black women are underrepresented in engineering doctoral programs (NSF, 2017) and how women of color in higher education can experience isolation and unwelcoming environments (Turner, Viernes, Gonzalez, & Wood, 2008). Current research has found that the creation of female peer or female-friendly environments encourage women to persist and continue doctoral programs, despite outside hardships and isolation that they may face (Bostwick & Weinberg, 2018). Several researchers have also found that experiences such as strong peer support could improve the persistence and belonging in STEM of underrepresented students (Chang, Sharkness, Hurtao, & Newman, 2014; Espinosa, 2011; Tate & Linn, 2005).
The purpose of this work-in-progress study is to examine how Black women create and leverage counter-spaces in an engineering education doctoral program. This collaborative inquiry study focuses on how women use a community of practice to cultivate academic and professional success. By expanding the focus of engineering to include a more diverse collection of scholars, the discipline of engineering would likely be enhanced by the expanded range of views. New thought brings additional philosophies, inquiries, perceptions, and skills (Wilson, 1992). This work in progress is designed to understand the experiences of four, diverse women to understand how they navigate their pathways as promising, future engineering education scholars by answering the following questions:

1. How do first-generation, Black female doctoral students navigate their pathway in an engineering education program?
2. How do women in these programs use counter-spaces to cultivate academic and professional success?

A collaborative inquiry approach was taken to examine the four women pursuing their doctoral degrees at a large university located in the midwestern region of the United States. The four women served as researchers and participants in this study.

**Theoretical Framework**

**Black Feminist Thought**

We draw on Black feminist thought (BFT) as the theoretical foundations to understand 1) how Black women navigate their pathway in engineering education doctoral program as first-generation doctoral students and 2) how Black women in engineering education doctoral programs use a counter-space to cultivate academic and professional success. BFT work aims to empower the voices of Black women in spaces where their voices are traditionally suppressed by the dominant culture (Collins, 2000). This framework emphasizes how the experiences of Black women across the diaspora should not be characterized as “identical experiences” or “normative,” instead it is essential to examine “Black women’s group standpoint regarding experiences associated with intersecting oppressions, stressing this groups heterogeneous” nature (Collins, 2000, p. 28). Collins described how Black feminist thought should bring attention to the lived experiences of Black women, in addition to identifying ways to improve their experiences and the use of dialogue to empower Black women as agents of knowledge. Our work uses a cyclic research-to-practice approach by using ongoing discussion with virtual communication technology to support one another, despite our physical location.

Feminist thought has been used to examine the experiences of Black women in engineering programs (Beddoes & Borrego, 2008; Wilder, Bertrand Jones, & Bertrand, 2013). Additionally, Charleston and colleagues (2014) identified three themes to describe the experiences of fifteen aspiring computer scientists: 1) challenges of being a Black woman in higher education, 2) commonality of isolation and subordination, and 3) sacrifices related to higher education and pursuance (Charleston, George, Jackson, Berhanu, & Amechi, 2014, pp. 171-172). Their work uncovers how the participants' intersectional identities as Black women influence how they are perceived by their peers who challenge their intellectual abilities as aspiring computer scientists; the participants experience feelings of isolation where the dominant group is white and male; the participants experience tension between the flexibility regarding the nature of the discipline and sustaining a social life. Likewise, Morton and Parsons (2018) demonstrated the use of an intersectional lens beyond the duality of being Black and female. Their work acknowledges the importance of saliency in how someone expresses themselves within a STEM context using poetic transcription such as “I am” to represent their leading identities in certain spaces (Morton and Parson, 2018, p.1377).
Methodology

In this paper, the researchers used collaborative inquiry (CI) to systematically explore our experiences as first-generation Black women pursuing a doctoral degree in engineering education in the United States to understand how the cultivation of academic and professional success through counter-spaces. By using a collaborative inquiry approach, the researchers are active participants and co-investigators, who are engaging in shared exploration to create new knowledge about the practices utilized to develop professional identities in counter-spaces to inform how to foster inclusivity in STEM doctoral programs (Donohoo, 2013; DeLuca, Shulha, Luhanga, Shulha, Christou, & Klinger, 2015).

This qualitative approach emerged through the investigation of educator professional development by combining aspects of action and participatory research (Cooper, 2006). CI is a cyclical process that is often described in stages. Although these stages vary depending on the investigation, the foundation of CI is a socio-constructivist perspective where the active participants/co-investigators engage in knowledge negotiation through sharing lived experiences, engaging in practical actions, and iterative reflection often with an emancipatory intent (Kasl & Yorks, 2002; DeLuca, Shulha, Luhanga, Shulha, Christou, & Klinger 2015; Donohoo, 2013).

In this initial work-in-progress, four of the five authors are active participants and co-investigators exploring their lived experiences as doctoral students. During the evaluation, we followed Donohoo’s (2013) model for collaborative inquiry. As a result, engagement in this research design helped inform the development of protocols to be utilized by the team as we continue the work of this project. In the first stage of Donohoo’s model, the authors framed the problem of the investigation. Next, the authors individually completed a journal prompt and participated in a group interview to document their lived experiences about their doctoral journey. In the group interview, the authors divided into pairs and took turns to interview each other using a semi-structured interview protocol. The interviews were recorded and then transcribed verbatim to ensure accuracy. Next, the authors followed Donohoo’s (2013) five-stages for analyzing data: organizing, reading, describing, classifying, and interpreting. Through this engagement with the data, the authors inductively and deductively coded the data while engaging in facilitated research meetings to discuss interpretations. In the facilitated research meetings, the authors discuss interpretations, underlying assumptions, and convergent or divergent themes. Throughout this process, the authors took meeting minutes and added additional reflective notes to help document the process for future use.

The context of the study

A few programs have been designed to recognize Black women, first-generation doctoral students. For example, the social media group, “Black Women PhDs” recognizes both women who hold terminal degrees, as well as graduate students at various stages of the doctoral program. In addition, there are nationally funded programs such as the Alliance for Graduate Education and Professoriate (AGEP) and the Dissertation Institute, and the Ph.D. project that are designed to help students of color throughout their academic and professional career (Hasbun, Matusovich, & Adams, 2016; Milano, 2005). Both social and physical models of support are necessary and relevant; however, some of these programs are not designed to help students who are early-career doctoral students, do not provide frequent contact to ensure the participants are comfortable, and not focus on Black women.

Because of these reasons, the group called elevateHER was formed. elevateHER is a safe space to be authentic, share experiences of success and challenges, and identify ways to overcome gaps in our knowledge about the pathway to the professoriate. The colloquialism, HER was purposefully embedded to represent the essence of “Black girl magic,” a phrase often used in Black culture. The definition of elevate is to raise or advance to a higher
position (Merriam-Webster, 2018). Hence, the purpose of elevateHER is to uplift the voices of Black women in the engineering education community.

Results

The data collected included virtual group recordings and two journal entries. The analysis of this data focused on four women resulting in two major themes: 1) The importance of diversity, equity, and inclusion in engineering and 2) The significance of creation and preservation of counterspace(s). Based on the full analysis, several sub-themes emerged which are outlined below:

Theme 1: Navigating in and throughout an engineering education program

The women described how their past experiences in academic, professional, and personal contexts influenced their decisions 1) to pursue a doctorate in engineering education and 2) as they navigate throughout the program. When the students were asked to describe what influenced their decision to pursue a Ph.D. in engineering education, one student discussed how there were a “lack of women” and “women of color” throughout her “educational journey.” In addition to her limited interactions with the faculty of color, she described how throughout her six years developing medical devices she was the only “female,” “person under the age of 40,” and “Black woman.”

Similarly, another student described how she experienced being a minority in the engineering workforce and “encountered several challenges.” As a result, both of these women found themselves seeking ways to informally educate children from minoritized groups to engineering by chartering an NSBE (National Society of Black Engineers) Jr. chapter (a chapter of NSBE for pre-college students), starting a non-profit organization, and tutoring first-year students. These experiences led them to transition from the engineering workforce to a doctoral program to enhance the educational experiences of future engineers in higher education and industry by being “visible,” despite the underrepresentation of Black women in STEM.

Contrary to the limited, if any, interactions with faculty of color described above, one student explained how she was exposed to engineering education through her department chair at her undergraduate engineering program. Before the arrival of her department chair, she described how she “tutored math courses,” until she received the opportunity to work as a departmental ambassador to aid in the transition of first-year engineering students to college. This student was always “intrigued with how people learn and curricula requirements in engineering;” however, she did not know whom to disclose those interests to within an engineering program. Her role as a department ambassador gave her access to the department chair where she could reveal her hidden interest, and the department chair exposed her to the field of engineering education. This experience demonstrates how early-career engineering students benefit from interactions with the faculty of color who can help shape their career trajectories through exposure to alternative career paths.

As the students navigate throughout the doctoral program, they each have sought out supplemental experiences to aid in their development as a scholar. For example, one student served as a visiting scholar with the REEFE (Rising Engineering Education Faculty Experience) program to gain experience with teaching, advising, and conducting independent research. Despite the positive aspects of the program, she was “confronted with tensions between her work in diversity and equity and the practical application” of her work on the campus. However, as the co-instructor in the class, she described how she “defaulted to the methods of the current faculty” and felt “silenced,” which resulted in her students and colleagues by not addressing the inequities in the classroom structure. This experience required her to reflect on how she can “practice what she publishes” for the broader engineering education community. Similarly, all of the women have selected research agendas that address diversity, equity, and inclusion concerns through multiple avenues. These avenues include the design of inclusive learning environments, the role of industry
involvement in informal programs for pre-college students, retention, and persistence of Black women and women of color in the workforce and promoting an engineering culture that is inclusive to diverse ways of knowing and being an engineer.

Theme 2: The Significance of the Creation and Preservation of Counterspace(s)

For the participants, informal counterspaces serve as a safe space for the participants; informal counterspaces serve as a means of support for them in three major areas: personal, professional, and academic. The following are sub-themes that developed from the four women’s experiences:

**Personally.** The women involved used informal counterspaces as a source of support, encouragement, friendship, and family. While confronting personal issues, whether it be familial, health-related, or other life-altering events. The informal counterspaces served as a haven where the doctoral students could share their personal experiences or challenges and receive support, guidance, or encouragement while going through those personal experiences. These informal counterspaces have served as safe spaces for the women where they can be vulnerable, authentic, and share their thoughts in a judge-free zone without worrying about how others will perceive them. One student indicated “having informal outlets during my Ph.D. has been a godsend. If I did not have a place to share my thoughts, gossip, laugh, cry, with women who do not judge me and show me true empathy, I would be lost. Informal groups, as well as therapy, has helped me through some of the dark times in the program.” Another student indicated that the informal counterspace served as a family away from home: “I think another benefit with our informal group for me is like support on a personal level as well. Um, being away from family, being away from my husband, sorry [apologizes for starting to cry], I’m emotional because I’m pregnant. I am going to try not to cry...Like, like going through this [first pregnancy], it’s a big change in my life when I’m away [from family]. So, you guys have been very supportive...It’s like a family away from home.” A different student described how her friendship with the other women has helped her evolve and grow personally: “I’ve gone through a lot of changes and you all not only helped me in my professional development but just and my personal development and who I am as a young woman. Um, and how I think about the world because I had a very narrow perspective and I’m still stretching. But, um, like being friends with y’all has just changed my perspective of the world. It made me think of a lot broader than what I did when I first came in here.” These results highlight how this counterspace supports multiple identities including their personal identity and status in society as women of color pursuing terminal degrees in a STEM discipline.

**Academically.** The women involved used informal counterspaces as a place to stay motivated and share knowledge about the doctoral process. From the beginning of the program, the students became closer and later formed a bond based on cultural connections. One student explained that their relationship was “helpful for getting through the first semester of our Ph.D. program...I sought an informal space to connect with like-minded women, as well as to discuss various ways to navigate throughout the program.” In addition, another student described the group as, “You all [the group] have given me advice and knowledge to make decisions regarding the program. For example, when it came time for me to select an advisor, all the information was beneficial, and even though you all gave me information about various individuals, you also encouraged me to go and talk to them [advisors] myself and to talk to other people before making my decision. So that was really helpful for me to get the insiders view.”

This informal space was also beneficial during isolating times in the program. As one student described, “a Ph.D. is lonely work. Having a group in the program that can relate to my pains because of the knowledge of our Ph.D. program has been invaluable. These women have helped me navigate difficult turns in the program while being there to laugh and cry with. I am forever grateful for them, and I hope I have been an anchor for them as well.” However, it was equally important for these women to have someone to celebrate with.
as well. “The goal-setting process and checking in and being able to celebrate the little wins.” The students described elevateHER as a space for peer-mentorship to assist one another with decision making, especially for first-year doctoral students who may need strategies to navigate a new academic program.

**Professionally.** The women involved used counterspaces to ‘crowdsource’ opportunities that are available after graduation. As one woman explained, “as we progress in the program, we meet with one another more often to discuss what is going on with us. We exchange resources for helping organize our research, identify opportunities for professional development, and for support.” The creation of this counterspace served as a way for these women to pay it forward to future Black women doctoral students who may experience difficulties transitioning to a doctoral program. One student said,

I want to leave what, you know, when, when I walk away from my professional for me here, what do I hope colleagues and students and you know, others remember if they were if they can only remember one thing. Overall, the support of the group was the most important in developing professionally. It is important for me to have [a group] to get to my goal.

As what the others have said, “it’s nice to be around people to check you and say, you are doing a great job.” These results highlight how this counterspace facilitates the exchange of resources and the importance of a communal experience to navigate a doctoral program to support their development as engineering education scholars.

**Discussion**

The purpose of this paper was to understand how black women navigate an engineering education program, as well as how the participants use elevateHER to mediate their journey. This work resulted in two primary themes 1) Navigating in and throughout an engineering education program and 2) The significance of the creation and preservation of counterspace(s).

The participants in our study described their motivation for pursuing a doctoral degree in engineering education. An underlying commonality for their interest in engineering education was based on their experiences as being black women in STEM in academia and the workforce. In addition to their gender and race/ethnicity, these women experienced difficulties based on their age in their prior experiences, as well as limitations based on their status as a graduate student. For each woman, these experiences created different perspectives and identified artifacts that influence how they navigate their doctoral journey as a graduate student and developing researcher. For example, for some of the participants who worked in industry, the experience of being the only one or one of a few fueled a desire to work in informal engineering spaces that promote access and education of populations from similarly diverse backgrounds.

On the other hand, for another participant, her experience of the need to be flexible and fluid across the margins of different environments in her academic journey has motivated her work in identity development within hybrid spaces. As a result, it is important for faculty in doctoral programs to understand that although the stories are not monolithic, it is essential to understand the previous experiences of Black women. This understanding will help the faculty of the doctoral program better understand the students’ decision-making process while improving the student’s engagement with career trajectories that align with their interests and values.

On the other hand, we discovered the second theme in this study is that Black female doctoral students utilize counterspaces to close gaps and holes they perceive are within the doctoral structure. These counterspaces are often informal and exist outside of the formal requirements of the doctoral program. These spaces are viewed as safe havens for Black women to be authentic and vulnerable about all aspects of life (e.g., personal, professionally,
academically). In these spaces, Black women do not have to monitor their behaviors and can be supported by other women going through a similar process. Also, the counterspaces created and maintained by Black women let Black women celebrate each other beyond the formal recognition of the process of the department. In this work, we are not proposing that all doctoral programs should try to formalize these spaces into the graduate community, but often these spaces operate in secret. As a result, we do recommend that faculty of doctoral programs should be aware of the reason these spaces operate and begin to reflect on the effectiveness of the initiatives they have formalized to support diverse students. The counterspaces Black women or any other student from a diverse background utilizes during their doctoral journey are significant indicators that the students believe they need more support to achieve their goals. Therefore, these spaces can be great starting places to improve the climate of inclusion within a department.

By including the experiences of Black women in the discussion about diversity, equity, and inclusion within a department, we can understand how to increase the rate of retaining Black female doctoral students in higher education as researchers and practitioners. The future goals of this research are to replicate this research process with additional Black women on their doctoral journey and alumni to gain a broader understanding of different types of counterspaces and their influence on attaining a doctoral degree. As this research continues, we hope to begin to characterize factors that influence success during the doctoral process to help engineering education departments create an inclusive climate that supports a diverse group of engineering researchers. As a result, this study will encourage engineering researchers and practitioners to strategically refine operational strategies to meet the needs of diverse groups while advancing impactful STEM programs that might more efficiently increase diversity (Moskal, Skokan, Kosbar, & Dean, 2007).

References


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Re-thinking the Industrial Engineering Curriculum in Light of Technological Changes

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Abstract: Technology has been advancing at a rapid pace and institutions of higher learning have to keep up with these changes so that they can produce the type of graduates that are required by industry. In order to achieve this, the curriculum has to be interrogated and where necessary redesigned in order to match the requirements of industry. In this paper, a survey was conducted on some targeted companies in the Western Cape with the aim of determining the relevant technologies used by industrial engineering graduates in their work. This was then compared to the industrial engineering curriculum of a South African institution which trains and produces such graduates. The research findings revealed a mismatch between the two and identified the specific technological gaps which currently exist. The paper ends off with recommendations for the way forward and provides suggestions for the rethinking of the curriculum in order to accommodate technological changes in industry.

Introduction
The technological requirements of industry are constantly evolving especially as more companies embrace the Industry 4.0 phenomenon. There is therefore a growing expectation that students who are leaving universities and entering the working space already have the required capabilities to make a useful contribution in their place of work. With this in mind, the question that arises is, “Are the current curricula taught at institutions of higher learning meeting the technological requirements of industry?” More specifically, is the current National Diploma offered by a department of Industrial and Systems Engineering (DISE) at a specific institution of higher learning in South Africa meeting these requirements? What are the technological capabilities of students required by industry and which technological capabilities are the students currently trained in within the curriculum?

The main aim of the research is therefore to interrogate the current curriculum of the National Diploma offered by DISE at the institution being researched, by blending in the technological requirements of industry. In order to fulfil this aim, the following objectives have been set out:

- To identify technological capabilities of students required by industry
- To identify technological capabilities that students are trained in within the current curriculum.
- To analyse the technological gap that exists and make recommendations for curriculum improvement.
Context

Industrial Engineering

The field of Industrial Engineering (IE) is a very broad engineering discipline. Industrial engineering is a branch of engineering concerned with the integrated, systematic design and operation of industrial processes and systems. To a greater extent, the field requires professionals who are skilled in organisational, development and optimisation techniques (Sackey & Bester, 2016).

The IE field is broad with graduates capable of making a difference in any environment where a system exists. As a result, there is a wide range of technologies IE practitioners need to expose themselves to. The emergence of the fourth industrial revolution (Industry 4.0) is changing the teaching and learning landscape in the field of industrial engineering as explained by (Sackey, Bester, & Adams, 2017). The growing instability in the business arena, advancement in Information Communication Technologies (ICT) and increased global competition have placed a demand on manufacturing enterprises to change their ways of doing business, while academic institutions need to realign their curricula. This trend also affects the field of IE where there is a need to identify the necessary adjustments which have to be made.

Industry Needs versus Engineering Education

The question of whether the current education system is meeting the needs of industry is continually being asked by many practitioners. It is of the utmost importance that education institutions remain relevant to the needs of the workplace. This is becoming more pertinent given the rapidly evolving needs of industry as companies struggle to keep up with customer demands and what their competitors are doing. A case study approach paper written by Arlett et al, (2010) addresses the fundamental question of how the higher engineering education sector can meet the graduate recruitment needs of industry. One proposed solution is for more practical hands-on activities and simulated industrial experiences to be created in the courses, with the acknowledgement that “one size doesn’t fit all”. This view is also held by the authors.

One field of engineering that constantly faces changes in terms of industry needs is that of software engineering. Universities have the challenge of keeping up with latest trends but have limited class time to teach their students. In the research done by Ng & Huang (2013), a noteworthy conclusion was made that universities cannot teach everything that industry requires when it comes to software engineering. What they propose instead is developing a framework that addresses the fundamentals and way of thinking that will help meet the ever-changing industry needs. Looking more specifically at industrial engineering, a study was conducted by Rokkjær et al. (2011) who assessed the industry needs of three European countries compared to what the institutions in those countries were teaching. The categories of Innovation and Technology, Environment and Sustainability and Human Factors Engineering were found to be needed in industry but not sufficiently covered in the industrial engineering curricula.

Existing Technology in the Curriculum

The traditional methods of teaching and learning have rapidly evolved in line with the advances being made in technology. This is particularly evident in the teaching of engineering courses where the main challenge is to replicate in the classroom, the technology that the students will meet when they go out into the workplace. Different branches of engineering have specific technologies that are relevant to their fields although many of the technologies cut across many fields. Certain subject areas within the typical industrial engineering curriculum lend themselves to the use of technology more than others. These subject areas include computer integrated manufacturing and industrial automation which are commonly taught through the use of laboratories that replicate an industrial environment to students (e.g., Lima, Prado, Massote, & Leonardi (2012). However, as the use of computers has gained in popularity, subject fields that are not necessarily technology intensive have also made use of technology.
A case in point is the field of Engineering Economy where the use of computer simulation software to perform Monte Carlo techniques has been shown to be effective as demonstrated by Coates & Kuhl (2003).

The use of smart mobile devices is the building block for the use of higher level technologies such as ubiquitous computing and augmented reality as predicted by Castro, Colmenar, & Martin (2010). These higher technologies are all part of the so-called Fourth Industrial Revolution which is now influencing every sphere of our daily lives. Teaching and learning practitioners are now incorporating mobile device applications into their curricula due to the growing presence of smart mobile devices in the classroom. Innovative mobile applications such as the App Inventor 2 by De Moura Oliveira (2015), are now common place in university teaching of engineering courses. This trend is expected to increase as mobile devices become more affordable and widespread.

**Research Method**

The research method chosen to answer the research questions was in the form of a survey and face-to-face interviews. The sample of respondents for this survey was industrial engineering professionals and graduates from the chosen institution. The results from the interviews were triangulated with questionnaires in order to identify technological capabilities of graduates required by industry, as well as to determine current industry-specific technologies. The same methodology was then used to identify technological capabilities that students are being trained in within the current curriculum, with instructors being used as respondents.

The questionnaires were divided into sections and contained mostly closed-ended questions and a few open ended questions for qualitative purposes. For the industry questionnaires, the first section required general information about the company including information about the departments that employed industrial engineering graduates. The second section required the respondents to identify the technologies that IE graduates used in the specified departments. The third section was asking for the learning and training strategies and the graduates' abilities and competences acquired through using the specified technologies. The last section then asked for more general recommendations and comments from the respondents that would enable students to come from university better prepared to use the technologies. The instructor questionnaire was more brief and required each instructor to indicate the subjects that they teach and the related technologies. For each identified technology, the instructor had to indicate, amongst others, the teaching strategy, purpose of learning the technology, student abilities and the related skills acquired.

The questionnaires were initially distributed with Google Forms® being used as the preferred distribution method. However, this method was discontinued after a few attempts due to the poor response rate and the unsatisfactory quality of the backend data received. An innovative data collection instrument was then developed using a freely available mobile based software called AppSheet® (“About AppSheet,” 2019). Observational note taking was additionally used to validate responses from the instructors with subject specific study guides being used at this stage. Data analysis of all findings was then conducted using Microsoft Excel's analysis tools.

In-depth face-to-face interviews were conducted with a total of seven companies in the Western Cape. The companies were chosen based on the historical relationship that exists with the institution in question. All the companies have at some point hired fully qualified graduates or students undertaking their internship from the institution. Interviews were also conducted with eight industrial engineering instructors from the institution. Each of these instructors have a good working knowledge of the course and the main subjects that are taught. The use of AppSheet in all the interviews allowed the authors to collect and populate the data in real-time. The companies also allowed the authors to take audio recordings and thereby have a rich source of qualitative data.
Survey Results

The task that the authors had was to establish the specific departments in which IE graduates worked in the chosen companies. As can be seen from Figure 1, the manufacturing departments employed the bulk of the IE graduates with Project Management, Quality Control and Sales & Marketing also contributing a significant percentage of the total. Of these departments, sales and marketing was the surprising one given that it is a service department. This indicates that employers are seeing the need for industrial engineering skills in supporting business functions as well. The information technology (IT) department was however underrepresented showing that employers are yet to appreciate the role that industrial engineers can play in that crucial field of the company which specifically deals with technology.

For each department that was identified, the next task was to identify the technologies that are used by their IE graduates. The word ‘technology’ has different meanings depending on the context in which it is used. The scope in which this word is used in this paper is guided by the research done by Cunningham, de Beer, & Williams (2014) who divide technologies according to sub-sectors and into low tech, medium tech and high tech. The technologies were subsequently grouped into eight categories as shown in Figure 2. Microsoft Office packages clearly had the lion’s share of the technology usage. These packages include mostly MS Word, MS Excel, MS PowerPoint and to a smaller extent MS Project and MS Visio. Even though MS Outlook was not included in the choices, it was observed that almost all the companies use it as their main tool for communicating via email. The next biggest chunk of technology usage was in Manufacturing Information Systems (MIS). This was a broad category which includes Enterprise Resource Planning (ERP) software such as SAP, SYSPRO and Siemens MIS Suite. MIS also included some relatively smaller standalone software such as Smartsheet and TORA. A closer look at the most commonly used technologies indicates that MS Excel is the most popular followed by MS Word and then AutoCAD as shown in Figure 3.

![Figure 1: Departments with IE Graduates](image-url)
For each identified technology, the respondents had to define some characteristics in terms of: training and learning strategies; the IE graduates’ abilities; where the technology is used; and lastly the competences or skills acquired. Table 1 shows a summary of this information with particular emphasis on the IE graduate’s abilities when they first enter the workplace. In other words, did the graduates have novice, basic or intermediate knowledge of the technologies when they arrived? The numbers in the table indicate the instances where the specific technology was rated in terms of graduates’ abilities. This then determined how much training was required and if the training moved them to a better ability in using the technology. The next question was to determine the competences acquired in the process of using the relevant technology. A summary of the top ten competences is shown in Figure 4. Productivity improvement, presentation, method and time study and data analysis stand tall amongst the rest of the competences.
As discussed in the Research Methods section, interviews were also conducted with instructors in the industrial engineering department in order to understand which technologies apply to the different subjects that they teach. The curriculum, which at the time of writing the paper was being phased out, ran over four semesters of teaching and one year of work integrated learning. As can be seen in Figure 5, Microsoft Office software is by far the most widely used technology. Computer-aided Design (CAD) software comes a distant second with the other software represented even less. A closer look at the most commonly used technologies indicates that MS Excel is the most popular followed by MS Word and then AutoCAD as shown in Figure 6.
The interviews also sought to understand the students' abilities in using the technologies by the time that the course was concluded. The abilities were classified into Novice, Basic, Intermediate and Expert as defined by the instructors as illustrated in Table 2. The instructor survey also established the top competences that the students develop in using the technologies. These competences are illustrated in Figure 7 where word processing, presentation and data analysis are the most prevalent.

![Figure 5: Distribution of Technology Categories in IE Curriculum](image)

![Figure 6: Top Technologies used in IE Curriculum](image)
Table 2: Student Technology Abilities in IE Curriculum

<table>
<thead>
<tr>
<th>Technology</th>
<th>Novice</th>
<th>Basic</th>
<th>Intermediate</th>
<th>Expert</th>
</tr>
</thead>
<tbody>
<tr>
<td>CAD Software</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AutoCAD</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid Works</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drawing tools and instruments</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drawing sets</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering drawing board</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Workshop machines</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Manufacturing Information Systems</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TORA</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS Office</td>
<td>1</td>
<td>5</td>
<td>21</td>
<td>9</td>
</tr>
<tr>
<td>MS Excel</td>
<td>1</td>
<td>2</td>
<td>5</td>
<td>4</td>
</tr>
<tr>
<td>MS PowerPoint</td>
<td>1</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS Project</td>
<td>1</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS Visio</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>MS Word</td>
<td>1</td>
<td>7</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Simulation</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ARENA</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WorkStudy+ 6 for Time Study</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7: Top Competences in IE Curriculum

Discussion

What follows now is a discussion and interpretation of the results obtained. The first observation to be made is that MS Office software is the most used technology in both the curriculum and in industry with MS Excel and MS Word leading the way. However, Manufacturing Information Systems have a much bigger portion of the technology usage in industry (14%) as opposed to the curriculum where the technology only occupies 2% of the total technology usage. This is a hardly surprising result given that MIS software is generally expensive and varied making it impracticable to teach in the classroom environment. This point is driven home further by the fact that almost all the companies confirmed that graduates come in as novices when it comes to the use of MIS software. Another technology mismatch is in the field of programming languages where companies indicated a need for graduates to have a knowledge and understanding of them. However, the teaching of programming languages was found to be absent in the current curriculum. In particular, companies showed an interest in the use of Visual Basic for Applications (VBA) which is the programming language of Excel and other MS Office programs. Through VBA, companies are looking for graduates who are able to manipulate large datasets from different sources in the company and produce information that can be used to solve complex problems. Other programming languages also have a role but were not pronounced in their usage.

With regards to the abilities of students when they leave university and when they start working as graduates, a few interesting observations were made. Firstly, in all the technologies none
of the graduates were identified as being experts in their use when they entered the workplace. This is in spite of them being classified as experts in certain technologies when they finish the course. A case in point is in the use of MS Excel where in five instances, the student was deemed to be at expert level. It is worth noting that the term expert has been loosely used to mean one with the special skill or knowledge representing mastery of a particular subject (Dictionary, 1996). The fact that most of the students were still at a basic or novice level of technology usage did not however translate into them receiving adequate training when they enter the workplace. In 41% of the cases, the technologies were identified as being self-taught as opposed to 59% of the cases where some kind of training occurs.

There was some general consensus in terms of the competences achieved or developed during the use of the technology. Data analysis, presentation, word processing and productivity improvement all ranked highly from an industry perspective and from the curriculum perspective, albeit in slightly differing proportions. That being said, one glaringly missing competence in the curriculum which ranked highly in industry was that of database design and development. Companies expressed a need for graduates who can work with software such as MS Access and the SQL programming language for managing large volumes of data held in company databases.

In addition to the quantitative data, there was also a lot of useful qualitative information collected from the survey. The following recommendations were made by some of the industry respondents:

1. Curriculum must include projects that allow students to use their own initiative and identify problems on their own.
2. The so-called softer skills, such as communication and presentation, should be emphasised in exit level courses. This will help graduates to survive the professional landscape where confidence and comfort when making presentations make a big difference.
3. Students need to have a general familiarity for a wider range of technologies.
4. Universities must look for cheaper software alternatives that can replicate the more expensive software that the graduates will use in industry. This principle can be used for teaching, for example, ERP software in the courses.

Concluding Remarks

The research set out to interrogate the industrial engineering curriculum taught at a South African institution of higher learning by looking at the use of technology and the students’ abilities in using it. This was compared to the current use of technology in industry by these students when they graduate and enter the workplace. It was found that even though there were many similarities between what the students are learning and what industry needs, there were many other mismatches that were identified. Similarities included the importance of MS Office packages such as MS Excel in both industry and the curriculum. Differences were found in the use of database design software, which was prevalent and required in industry but absent in the curriculum. There was also a mismatch in terms of the students’ technological abilities when they finished the course and their abilities when they entered the workplace as graduates. Possible reasons for this mismatch were given and recommendations from industry were given on how to enable students to be better prepared for the use of technologies that are required in industry.

In light of this research, the next step is to validate these results by possibly comparing the findings from this study with companies in other regions of South Africa. The authors predict that similar research findings will be realised although also keeping in mind that one size doesn’t necessarily fit all. The next question would be how to best incorporate these missing needs of industry into the industrial engineering curriculum from a technology perspective. In order to achieve this, a framework on curriculum development and student learning abilities
will have to be researched and developed. It will also be worthwhile to conduct a research study which focused on developing a framework that changes the way of thinking of industrial engineering graduates so that they can adapt to any technological changes that they encounter in the workplace.

References


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Technology-Mediated Resources as a Substitute to Human Resources: Experiences of International Undergraduate Students in an Active, Blended, and Collaborative (ABC) Classroom in the USA

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Abstract: With the call for increasing student diversity in engineering courses, it is important to conduct research on evidence-based teaching practices that could address the unique challenges encountered by international students in the USA. In this study, we examine the experiences of international undergraduate students taking a core mechanical engineering course in an Active, Blended, and Collaborative (ABC) environment. We adopt a qualitative research approach based upon thematic analysis to explore the students’ experiences in this complex pedagogical framework and analyze how they use the different facets of the ABC learning resources to address the various challenges that they encounter in the course. Our results show that international students preferred to use the immediately accessible non-human resources made available to them in the course. Furthermore, international students were reluctant to interact with the instructor both inside and outside of the class. The technology-mediated resources provided on the course website helped the students to clarify any misunderstandings that they developed due to the language barrier in the classroom. In general, undergraduate STEM instructors could utilize pedagogical innovations such as ABC learning to help international students cope with some of the challenges that they face while navigating through their undergraduate STEM experience in the USA.

Introduction
The enrollment of international undergraduate students in the United States of America (USA) has steadily increased in the last two decades. The 2014-2015 academic year observed a record high of approximately 975,000 international students, which is a 60% increase since the year 2000 (Hartshorn, Evans, Egbert, & Johnson, 2017). Although studying in the USA may provide international students with many exciting prospects, they also face many challenges adjusting to a new culture and adapting to American university classroom norms. International students have been reported to struggle due to the lack of proficiency in spoken English and unfamiliar expectations, such as the need to actively engage in group work in the classroom and get academic help from their instructors and peers. (Heng, 2018; Perry, 2016). Furthermore, undergraduate students in the USA often encounter additional challenges when they enter their sophomore year and take core engineering courses that they perceived to be complex and difficult (Huang & Fang, 2013).
The Dynamics course considered in this study is often regarded as one of the most difficult courses that engineering students take during their undergraduate study (Huang & Fang, 2013). The Dynamics course of interest here was taught at a large mid-western university in the USA using a combination of Active, Blended, and Collaborative (ABC) learning pedagogies that were integrated to help students navigate the learning process and succeed in the course (Rhoads, Nauman, Holloway, & Krousgrill, 2014). Prior quantitative and qualitative research on this environment determined that the students’ course performance and experience in the course benefited from the multiple, aligned learning resources that the course offered (Kandakatla et al., 2019), which mirrors findings in the higher education literature on alignment (Reeves, 2006) and the benefits of multiple representations of concepts (Ainsworth, 2008). At the same time, though, international students had significantly lower course performance than domestic students (DeBoer et al., 2016), even controlling for prior academic performance. Because of this, we explored the experiences of international students in the Dynamics course as they represented approximately 20% of the class population. It was important to understand how the ABC environment and its associated resources met the unique needs of international students in the course. In this paper, we asked the following research question:

RQ: How do international students in a core engineering course describe their experience with the multiple resources available to them in an ABC learning environment?

Our goal was to understand how international students used the learning resources to tackle some of the academic and cultural challenges that they might have faced in a core engineering course in the USA. The results from this study will contribute to the literature of evidence-based teaching practices that are being implemented to meet the demands of an increasingly diverse student body in engineering courses.

Background

Challenges faced by International Students in the USA

Prior studies demonstrate that international students face a number of common challenges while pursuing higher education in the USA. International students who come from non-English speaking countries and lack proficiency in the English language struggle to socially adjust and succeed in their programs (Andrade, 2006). The language barrier can also inhibit learning in the classroom, as international students might be reluctant to interact with their instructor and peers (Liu, 2016). Outside of the classroom, international students often find it hard to become friends with domestic students and prefer to form communities with individuals from the same nationality (Zhao, Kuh, & Carini, 2005). International students as a result were not comfortable seeking academic or personal support from the majority of their peers who are domestic students.

Another challenge encountered by international students is getting accustomed to the open-ended teaching methods commonly employed in the USA (Heng, 2018). Students reported that instructors in the USA emphasized both interaction with, and the active participation of, students in the classroom (Liu, 2016). Liu reported that Chinese international students struggled during classroom interactions, as they tended to take more time to plan what they should say to others. Other studies have observed that international students encountered challenges when technology was integrated into their courses. For example, the learning management systems that might be customary to (or previously used by) domestic students were perceived as unfamiliar technology by international students (Habib, Johannesen, & Ogrim, 2014). Heng reported that international students, to overcome some of the aforementioned challenges, spent more time preparing before and after class, and while studying for exams (Heng, 2018). International students were also observed to use a range of learning techniques and self-help strategies, such as multi-tasking, that helped them cope
with their difficulties and succeed in the program.

**Active, Blended, and Collaborative (ABC) Learning**

There are many prior studies that highlight the benefits of implementing active, blended, or collaborative pedagogies on students’ learning. Freeman et al. conducted a meta-analysis of 225 studies that used a variety of teaching techniques and found that the examination scores of students in active learning classrooms improved by 6% when compared to those who were taught using one-way lecturing (Freeman et al., 2014). Active learning further contributes to students’ learning by helping them reflect more deeply on the course content (Presadă & Badea, 2014). The use of active learning techniques instills creative and critical thinking among students in a course (Simons, Linden, & Duffy, 2000). Collaborative learning is often considered a subset of active learning and requires students to work in teams to complete a specific task. Collaborative learning has been shown to build critical thinking skills (Schamber & Mahoney, 2006), better communication and groupwork skills (Terenzini, Cabrera, Colbeck, Parente, & Bjorklund, 2001), and improve student engagement and retention in undergraduate courses (Preszler, 2009).

To incorporate blended learning, instructors need to combine face-to-face and online instruction to provide students with technology-mediated support outside of the classroom (Garrison & Vaughan, 2008). Blended learning often provides students with multiple learning resources and has been observed to sustain students’ cognitive engagement in a course (Gyamfi & Gyaase, 2015). Other studies have found that the integration of blended learning into a students’ classroom experience positively impacts their performance and decreases student attrition (López-Pérez, Pérez-López, & Rodríguez-Ariza, 2011). A student’s usage of blended technologies was however observed to vary depending on their demographic characteristics. For example, international students that were new to the idea of blended learning and unfamiliar with educational technology found it challenging to get accustomed to the course at its beginning (Prasad, Maag, Redestowicz, & Hoe, 2018). However, students slowly adapted to blended learning depending on the perceived ease of use and usefulness of the technology tools utilized in the course. The Dynamics course considered in this study had combined the ABC pedagogies, which as prior literature suggested were perceived to be unfamiliar to international students. We therefore investigate how the international students made use of the various ABC learning resources to navigate and succeed in the course.

**Classroom and Institutional Context**

Purdue University is a large Midwestern university that features one of the largest proportions of international students among public universities in the USA. The undergraduate Dynamics course (taught in an ABC learning environment) was offered by the School of Mechanical Engineering at Purdue University and students typically took the course in their sophomore year. Instructors teaching the Dynamics course combined Active, Blended, and Collaborative pedagogies into a single learning environment to provide students with a range of digital and non-digital learning resources (Rhoads, Nauman, Holloway, & Krousgrill, 2014). Students were provided with a hybrid “Lecturebook” in place of a Dynamics textbook. The Lecturebook included equations, example problems, conceptual questions and extensive empty white space for students to take active notes in the classroom.

Students had access to a course website that served as a repository for videos of the Dynamics problems solved in the class (referred to as lecture example videos), solution videos of homework problems (referred to as homework solution videos), and live-action demonstrations of dynamics concepts (referred to as Visualizing Mechanics videos). The blended resources provided the students with support outside of the classroom. The instructors encouraged the students to seek advice from, and provide support to, their peers by implementing collaborative learning activities in the classroom. Students were asked to collaborate in groups of 3–4 to work on in-class quizzes throughout the semester. The
instructors made available an online discussion forum on the course website to promote student interaction outside of the classroom. The discussion forum was organized as separate discussion threads for every homework problem, and the students used the discussion forum to interact with their peers while solving and submitting homework three times a week. The students were also provided with office hours to meet the instructor and tutorial rooms which were staffed with teaching assistants who were available for more than forty hours per week.

Methods
Data Collection
The participants selected for this study were international students who took the Dynamics course in the semesters ranging from Fall 2015 to Spring 2017. Based on the data provided by the Office of Institutional Research, Assessment, and Effectiveness (OIRAE) at Purdue University, international students represented approximately 20% of the class population during these semesters. The data were collected using semi-structured interviews conducted during the last week of the semester, and 17 international students from multiple semesters completed the interviews. We could not identify the nationality of the students as the institutional research database we drew from does not include the country of origin of international students. The students were interviewed from multiple semesters as we hypothesized that the experience of students might vary based on the instructors who taught the course. While the ABC learning resources made available to the students were consistent across all of the semesters, the extent of active and collaborative learning activities implemented in the class was dependent on the instructor. The interviews with the students were audio recorded and later transcribed using a third-party vendor.

Data Analysis
Qualitative methods were used to examine the experiences of international students in the Dynamics course. Thematic analysis was conducted to analyze the interview data and a six-phase process, as recommended by Braun and Clarke, was followed (Braun & Clarke, 2006). The first two steps involved developing a codebook and then coding all the interview transcripts using the codebook. Two different researchers coded the interviews using the codebook and then manually checked for interrater reliability in the coded data. A reliability of over ninety percent was achieved by the researchers, which met an acceptable level (Miles, 1994). In the next phases, overarching themes were identified by sorting the list of codes and searching for the commonalities between them. The themes were later reviewed to look for the relationships between the codes inside and across different themes. The results from the thematic analysis are presented in the next section along with exemplary data extracts.

Results
Four major themes emerged from the thematic analysis of the semi-structured interviews. Each theme is described by providing relevant data excerpts from the student interviews. The themes highlight how, and why, international students utilized the various digital and non-digital resources made available in the course.

Theme 1 – Reticence to Interact with the Instructor
Students in the Dynamics course could interact with the instructor inside and outside of the classroom. The instructors facilitated the active engagement of students by encouraging them to ask questions inside the classroom. Prior research that measured and categorized the various events in the Dynamics classroom throughout a semester reported that 10% of the class time was spent on the students asking the instructor questions (Evenhouse et al., 2018). However, the interview responses of the international students revealed that they were often reluctant to interrupt the instructor during the class hours: “I'm the kind of person who doesn't feel very comfortable while the lecture is going on, so I don't ask a lot of
“questions.” If a student did not understand something in the class, they preferred to seek help from a neighbouring peer instead of the instructor. The international students’ discomfort in communicating with the instructor in the classroom could be a consequence of certain cultural norms that restrain them from interrupting the instructor while they are teaching (Johnson, 1997).

Students could meet the instructors outside of the class by visiting them during the scheduled office hours. However, many of the international students interviewed reported that they did not visit the instructors during office hours. One student felt intimidated by the instructor: “I rarely approach the professor... I’m like a bit intimidated to approach him and sometimes I don’t want to ask stupid questions.” Other students shared similar experiences where they preferred going to the tutorial room or reaching out to their peers for support. It is important to note that while this specific theme emerged from the interviews of international students, the reluctance to meet the instructors during office hours also emerged across the entire student population in the course, which includes a majority of domestic students (Wirtz et al., 2018). In addition, the timings of the office hours often conflicted with the students’ schedule as one student said, “Since I have classes almost 15 hours a week, I do not have a lot of time to go to the office hours of the professors. There might be a lot of students whose [schedule] clash with professor’s office hours. I think the online resource really helps. It helps me work in my own convenience, like in my apartment or in the library.” Students therefore did perceive the tutorial rooms to be an immediately accessible resource.

Theme 2 – Individual Study Strategies Preferred over Group Engagement

The majority of the international students, when asked about their study habits outside of the classroom, preferred to study individually instead of in a group. For instance, several students mentioned working on the homework problems by themselves, such as: “I've always done it all by myself, all the homeworks and stuff.” Students who were open to collaboration limited the number of members in the group to two or three and generally worked with individuals they knew prior to taking the class. For example, one student took help from his friends who had completed the Dynamics course in the previous semester: “Most of the time I study alone. But sometimes I have friends who already took their ME Dynamics [Dynamics course] before this semester, so I approach them and ask them questions... If they still have resources from their semesters, I can use them and study or just ask them for help on something.” Another student mentioned similar instances when she preferred to seek help from her roommate (who took the Dynamics course in the previous semester) instead of reaching out to a peer currently enrolled in the class.

Some students made use of the online discussion forum to collaborate with peers outside of the classroom. The online discussion forum was available to students as a separate discussion thread for each homework problem. Students could post and reply to the queries submitted by their peers on each of the homework problems. International students who did not want to collaborate with peers in person used the discussion forum to interact with peers outside of the classroom: “I prefer to study individually for exams or homeworks, but I sometimes will ask questions on the blog because I don’t want to sit together with my peers.” Students also noted that they would utilize the discussion forum (an individual, asynchronous resource) when they needed help and wanted to avoid going to the tutorial room (a group resource in a particular location at a specific time): “I used it [discussion forum] probably once a week when I had some doubts and didn’t want to go to the tutorial room.” It was observed that they preferred to first use the blended or technology-mediated support and later resorted to various human resources such as peers, teaching assistants in tutorial rooms, and the instructor.

Theme 3 – Blended Resources Provided Support to Clarify Misunderstandings Developed Due to the Language Barrier in the Classroom

Students were provided with a range of online videos to support them in their learning process outside of the classroom. One of the most highly used resources was the lecture
example videos that contained the recording of the problem-solving techniques that the instructor taught in the class. Some international students from non-English speaking countries utilized the lecture example videos to address any misunderstandings that they attributed to the language barrier: “Because I am not an English native speaker, sometimes I will misunderstand some problem statements and even misunderstand some formula. So, I think the lecture examples [videos] help me reflect while solving homework problems.” One student believed that the utility of the lecture example videos was sometimes higher than the classroom lectures because she could regulate the speed and pause the videos when necessary.

Other students who could not keep up with the pace of the instructor in the classroom utilized the lecture example videos in a similar way. A student compared their experience in Dynamics with other courses that did not have the lecture example videos: “When I took Statics, there was no lecture example videos. They instead had the presentation and lecture slides. They can be helpful, but sometimes because you don't hear the explanation [in the classroom], so they could become confusing.” When students missed a specific classroom session, the online videos provided them with some flexibility to learn the course topics that they missed. However, the students acknowledged the need to attend all of the classroom lectures: “we still have to go to classes because the professor might explain the concepts in different ways, so you can understand better. But you can also access the extra resources to get better understanding of the class materials.” While the lecture example videos might be valuable to all of the students in the Dynamics course, international students appear to benefit more from this resource, as they were observed to be reluctant to seek help from the instructor and their peers. The lecture example videos therefore provided the students with a convenient technology-mediated platform to revisit the content that was taught in the classroom.

Theme 4 – ABC Resources Allowed Students to Form a Range of Self-Regulated Learning Techniques

The availability of multiple resources allowed international students to self-regulate their learning and form study habits that helped them solve homework problems outside of the classroom. Working on homework problems was integral to the students’ success in the Dynamics course, as they were expected to submit homework problems three times per week. Students reported the use of various non-human resources (Lecturebook, lecture example videos, homework solution videos, and the discussion forum) in varied ways to seek help and submit the homework problems every week. Students used the hybrid Lecturebook to find examples of problems that were similar to those provided in the homeworks, and then they viewed the lecture example video that was associated with that example. One student said, “I would try and solve it by myself first, and then if I can't, I will look at the textbook [Lecturebook] for the lecture notes that I wrote during the class. If I can't find it, I will look for a similar lecture example problems, and try to watch them online. Those are pretty helpful. Usually, from there I can find my answers.”

The online discussion forum was another resource that was intended to help the students while solving the homework problems. If the students could not find the necessary help after using the lecture example videos, they looked for support on the discussion thread that was created for that specific homework problem. Even if they preferred not to post any questions, the students mentioned receiving help by reading through the comments that were posted by their peers. After submitting the homework, video solutions of the homework problems were made available to the students for review. Students who could not understand how to solve the homework problems utilized the homework solution videos after they were released: “I think it's really useful [homework solution videos], because, again, if you don't understand how to do a homework, you just go back once it's released and watch the video, and then you know what to do it for in the future.” Interviews conducted with domestic students reported similar self-regulated learning patterns as mentioned by the international students where they utilized the Lecturebook, lecture example videos, and the discussion forum in
tandem with each other (Kandakatla et al., 2019). However, domestic students were observed to also utilize the human resources (peers, tutorial rooms) made available through the learning environment when necessary.

Discussion

The themes that emerge from our analysis of international students' experiences delineate a pattern of study strategies that international students use to complement and substitute for learning resources they do not perceive as beneficial. Although some of these strategies mirror preferences we have observed in the whole class population (majority domestic students), international students report technology-mediated, rather than peer-based, supports as the type of resource they turned to as a coping strategy. International students were observed to not seek support from the instructor and their peers (Themes 1 and 2), both of which were considered to be key resources in the course. The students' reluctance to ask questions and interact with the instructor in the classroom is consistent with prior literature that suggests that international students from home countries in Asia and the Middle East might be accustomed to different classroom norms such as non-participatory teaching methods (Lin, 2012; Woods, Jordan, Loudoun, Troth, & Kerr, 2006). The international students' reticence to meet with the instructor during scheduled office hours was similar to the help-seeking pattern of the domestic students in the course, who were seen to only seek support from the instructor as a last resort (Kandakatla et al., 2019). Domestic students, however, often met with their peers outside of the classroom and visited the tutorial rooms to seek help while solving homework problems or while studying for exams. The international students, in contrast, preferred to work individually and made use of the technology-mediated resources that were available to them in the course (Themes 3 and 4). As a result, international students formed study habits using the technology-mediated blended and collaborative learning resources and coped with a reluctance to utilize the human resources (instructor, peers, teaching assistants) that were available in the course. The discussion forum (a blended and collaborative resource), for example, allowed students to virtually seek support from their peers instead of meeting with them outside of the class. The availability of technology-based learning resources could therefore help international students self-regulate their learning and overcome the challenges of not having a large peer support group.

Limitations

One of the major limitations of this study was the generic identification of all the participants as international students due to the unavailability of data on their nationality. The absence of data limited the scope of our research as we were unable to conduct more fine-grained analysis of the participants' responses. Some of the participants' experiences could have been a result of cultural or social norms that are specific to certain nationalities or geographic regions. We were unable to differentiate the experiences of the students across different nationalities and as a result we were limited in our level of analysis.

Conclusion

This qualitative study contributes to the literature on the experiences of undergraduate international students in the USA. We examined how international students made use of a suite of learning resources in a core mechanical engineering course that incorporated an active, blended, and collaborative learning environment. It was observed that students preferred to utilize the digital resources over more immediate human resources, such as the instructor, peers, and teaching assistants. They made use of the digital resources to supplement and navigate challenges such as language differences or divergent cultural capital making quick formation of peer groups with domestic students difficult. The blended component of the learning environment allowed the students to review the course content and form self-regulated study habits to succeed in the course. Universities in the USA that
have a high enrollment of international students should encourage instructors to thoughtfully integrate and align technology into their courses. This would provide the students with additional avenues to seek support as they navigate through the complex academic challenges in undergraduate engineering programs.

References


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Using Self-determination Theory to Evaluate Faculty Professional Development Programs

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Abstract: This paper discusses the challenges of assessing faculty professional development programs and proposes using the self-determination theory to guide the development of an instrument to assess such programs. Previous experiences have shown that some professional development programs may become transformative learning experiences. These programs present unique challenges for assessment. Since the participants may experience a shift in their understanding of specific concepts, they may feel less competent after they have actively participated in a set of learning activities regarding those concepts. In this study, we propose measuring participants’ perceptions of the three psychological needs suggested by the self-determination theory: autonomy, competence, and relatedness. The participants of a professional development workshop on instructional design completed a pretest/posttest instrument designed to assess changes in their perceptions about autonomy, competence, and relatedness in the context of instructional design. This paper presents the preliminary validation of the instrument using factor analysis, checking for internal consistency, and assessing convergent and discriminant validity. Based on the results from these analyses, the research team proposes future directions for the refinement of the instrument and the assessment of professional development programs.

Introduction

Three years ago, we started to offer professional development workshops for Colombian engineering faculty members interested in improving their teaching practices, and perhaps start diving into the scholarship of teaching and learning and engineering education research. In REES 2017 we presented the challenges we faced while assessing these workshops, which became transformative learning experiences (Ortega, Vieira, Sanchez-Pena, Streveler, 2017). Participants’ understanding of concepts like “instructional design” changed throughout the workshops and therefore, their perceptions about their competence as instructors before and after the workshops were not comparable.

On a second iteration of the workshops and the survey instrument, the research team collected additional data using open-ended questions (Ortega, Vieira, Sanchez-Pena, Streveler, 2018). Answers to these questions showed how the participants’ understanding of the instructional design process and of how people learn changed as consequence of the workshop. In general, the participants felt that they were developing a set of skills, but also that the way they perceived teaching and “learner-centered instructional design” changed. The faculty members also mentioned that their participation in the professional development program made them feel part of a community of faculty members interested in education.

Based on these findings, the research team adopted the self-determination theory (Deci, Koestner, & Ryan, 1999; Deci, &Ryan, 2002) as the guiding framework for designing the instrument to assess the third iteration of the professional development workshop. This
approach enabled us to measure how participants’ autonomy, competence, and relatedness changed at the end of the program. The goal of this paper is to develop and preliminary validate an assessment instrument for faculty professional development programs. The guiding research question for this study is: How can the self-determination theory inform the assessment of faculty professional development programs?

Background
Transformative Learning
Over 40 years ago, John Mezirow coined the term transformative learning to characterize the experiences of adult learners returning to higher education after a long time out (Kitchenham, 2008). Transformative learning involves a deep change in the assumptions, values, and views of the learners. The trigger of such changes is known as perspective transformation. While in his seminal work Mezirow identified 10 stages conducive to perspective transformation, the process can be summarized into three major elements: (1) critically reflect on assumptions; (2) use empirical evidence or critical discourse to explore the assumptions; and (3) act aligned with the transformed perspective (Mezirow, 2006). We believe that at least two out of these three elements were present in the workshops designed for educators as learners, which challenged their teaching strategies with evidence-based practices and allowed them to critically discuss their practice with other participants and the instructors as well.

Assessment of Faculty Professional Development Programs
The assessment of professional development programs for educators draws from the general literature on the assessment of professional development programs (PDP). A widespread framework for the assessment of PDP in the U.S. has been the work of Guskey and Sparks (1991), which in turn drew from the organizational ideas of Donald Kirkpatrick (2006). Building upon his own work on the assessment of PDP, Guskey (2000) advanced and refined a model for the assessment of PDP for educators that looks at results on five levels: (1) participants’ reactions; (2) new knowledge and skills participants gained; (3) organizational support participants have; (4) influence of new knowledge in participants’ professional practice; and (5) impact on student achievement. This model, known as the Critical Levels of Professional Development, has informed the design of traditional assessment instruments for professional development initiatives at the university level (Mullins, Lepicki, & Glandon, 2010). However, some educational researchers have encountered that PDP for educators can become transformative learning experiences (Kitchenham, 2006; Ortega, Vieira, Sanchez-Pena, Streveler, 2018). In such cases, traditional assessment falls short in providing an accurate picture of the results achieved. To overcome this pitfall, some scholars have designed and administered assessment instruments based on the tenets of transformative learning (King, 2009), with varied results (Snyder, 2008). Notably, at the intersection of transformative learning and assessment of informal instruction, Goulet (2010) posed that transformative learning can be fostered and captured through participants’ self-assessment. The research team believes that an assessment instrument informed by the self-determination theory can spark self-assessment and capture the potential transformation of participants’ perspectives.

Theoretical Framework
The self-determination theory describes people’s motivation to engage in a task or activity as a continuum (Gagné & Deci, 2005). Someone can be not motivated at all, or she can be extrinsically or intrinsically motivated (Ryan & Deci, 2000). The extrinsic motivation requires of external factors that influence your interest to participate in a specific activity or task. For
instance, a student may complete the homework assignment just because it is graded. In this case, the external motivation is the reward given by the grade. In contrast, the intrinsic motivation refers to an interest to engage in the activity or task, and devote more time to it, just because the task itself is interesting for the individual (Lee, Lee, & Hwang, 2015). While we often use extrinsic motivation to engage students and faculty members on specific tasks, the intrinsic motivation is more desirable. When the task is interesting itself, external rewards could jeopardize the achievement of the learning outcomes (Hagger & Chatzisarantis, 2011).

There are three psychological needs that affect someone’s motivation towards a task: (1) autonomy; (2) competence; and (3) relatedness. This is the case for different contexts, even if the culture is not an individualistic one—particularly in the case of autonomy (Deci & Ryan, 2008). Autonomy refers to the extent to which the individual can make decisions or has control on how to approach the task. Competence relates to the individual’s perceptions about her ability to complete the task, also described as self-efficacy (Bandura, 1989; Ryan & Deci, 2000). Finally, the psychological need for relatedness describes how the person feels part of a community interested in the task. The satisfaction of the need for autonomy promotes the processes of identification and integration, required for internalization and extrinsic autonomous motivation (Gagné & Deci, 2005).

The individual satisfaction of these three needs promotes intrinsic motivation, which in turn yields to several outcomes: (1) maintained behavior; (2) effective performance; (3) job satisfaction; (4) positive attitude; (5) organization citizenship behavior; and (6) well-being. Developing only one of these psychological needs, though, is not enough to promote intrinsic motivation (Ryan & Deci, 2000). An individual that feels competent but does not have any autonomy on the task or does not feel part of a broader community, might not be intrinsically motivated to engage in the task. Hence, this project proposes that the assessment process of professional development programs should go beyond the competence of the participants and identify whether other variables like autonomy and relatedness are also changing. By participating in professional faculty development programs, the participants may be able to identify the autonomy (or lack of autonomy) they have for course design, or they may get involved into a community of practice with other participants in the program.

**Methods**

**Procedures**

The research team conducted three professional development workshops in 2018 at three different Colombian universities (institutions A, B, and C). The three institutions are considered to be medium to large institutions in Colombia. Institution A is a private university and counts with over 7000 students, mostly undergraduate students (86%). Institutions B and C are public universities, with over 50000 students (82% undergrads) and over 16000 students (98% undergrads) correspondingly.

Figure 1 shows the two different workshops we offered in 2018. The first workshop was focused on the instructional design process, using backwards design (Wiggins & McTighe, 1998) as the guiding framework. The learning outcomes of this workshop were: (1) Design instructional experiences for an innovative class based on the techniques discussed in this course, using a topic and a method of your interest; (2) Write appropriate learning objectives, coherent with the dimensions and levels of knowledge of the curricular priorities of a course; (3) Critique the soundness, suitability, and outcomes of hypothetical and real implementations of innovative teaching methods according to their stated aims; and (4) Discuss the suitability of documented educational practices (assessment and pedagogies) for the local context. The second workshop was an introductory course on educational research methods, and we used design-based research as the guiding framework. The learning outcomes of this workshop were: (1) Analyze the use of different research paradigms and methodologies typically encountered in social and educational research; (2) Differentiate the fundamental elements of educational research using the framework of
Design Based Research (DBR) to make sense of their purpose and importance; (3) Write the draft of a cohesive plan for educational research in the classroom following the guidelines of DBR; and (4) Recognize the different areas and venues of educational research. While institution A only implemented the workshop on design-based research, institution B implemented both workshops, and institution C only implemented the workshop on backwards design.

Figure 1: Content of the professional development workshops

For the scope of this paper and the validation of the instrument, we will only use the data corresponding to the workshop on instructional design (i.e., institutions B and C). Approximately 17 faculty members participated in the program at institution B, while 60 faculty members participated in the workshop at institution C.

Data Collection

We adapted an existing instrument (Van den Broeck, Vansteenkiste, De Witte, Soenens, & Lens, 2010) that was designed to capture autonomy, competence, and relatedness at work, and was originally developed in English. The first author of this paper did the initial translation and adaptation of the instrument to the context of instructional design. The second author reviewed the translated instrument and suggested specific clarifications in some of the questions.

The questionnaire consisted of 15 five-level Likert-scale questions, five for each construct. Some questions within each construct were worded from a reversed standpoint to check the reliability of the answers provided by every single participant. Surveying the need for autonomy construct included questions related to who chooses what to include/exclude within their course, whether the participants are forced to include content they deem irrelevant, and whether they can propose changes to the syllabus of their courses. Table 1 describes the items for autonomy, both in Spanish and in English.

The items measuring the construct related to the need for competence asked participants how prepared they felt to design courses, how much they knew about instructional design, and how confident they were about their teaching performance. Table 2 describes the items related to the construct of competence for instructional design.

Finally, the need for relatedness construct was measured using five items that asked participants how connected or disconnected they felt to their colleagues, and whether they talked to each other and supported each other in the process of instructional design. Table 3 describes the five items (in Spanish and in English) to measure relatedness in this context.
Table 1: Items measuring autonomy for instructional design

<table>
<thead>
<tr>
<th>Variable</th>
<th>#</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autonomy</td>
<td>Q1</td>
<td>I am free to design my courses based on my ideas / Tengo libertad de</td>
</tr>
<tr>
<td></td>
<td></td>
<td>diseñar mis cursos según mis ideas</td>
</tr>
<tr>
<td></td>
<td>Q2</td>
<td>I can propose micro-curricular changes in my institution / Puedo proponer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cambios micro curriculares en la institución</td>
</tr>
<tr>
<td></td>
<td>Q3</td>
<td>The department head makes important decisions about the instructional</td>
</tr>
<tr>
<td></td>
<td></td>
<td>design of my courses / Los directivos docentes del departamento toman</td>
</tr>
<tr>
<td></td>
<td></td>
<td>decisiones importantes sobre el diseño de mis cursos</td>
</tr>
<tr>
<td></td>
<td>Q4</td>
<td>I can freely choose what is the best way to design my courses / Puedo</td>
</tr>
<tr>
<td></td>
<td></td>
<td>elegir de manera independiente cuál es la mejor manera de diseñar mis</td>
</tr>
<tr>
<td></td>
<td></td>
<td>cursos</td>
</tr>
<tr>
<td></td>
<td>Q5</td>
<td>I often need to include irrelevant content in my courses / A menudo tengo</td>
</tr>
<tr>
<td></td>
<td></td>
<td>que incluir en mis cursos contenidos que no considero relevantes</td>
</tr>
</tbody>
</table>

Table 2: Items measuring competence for instructional design

<table>
<thead>
<tr>
<th>Variable</th>
<th>#</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Competence</td>
<td>Q6</td>
<td>I am not sure what is an appropriate process for designing my courses /</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No tengo muy claro cuál es un proceso adecuado para diseñar mis clases</td>
</tr>
<tr>
<td></td>
<td>Q7</td>
<td>I feel prepared to design my courses / Me siento preparado para diseñar</td>
</tr>
<tr>
<td></td>
<td></td>
<td>mis cursos</td>
</tr>
<tr>
<td></td>
<td>Q8</td>
<td>I consider myself to be good in my teaching responsibilities / Considero</td>
</tr>
<tr>
<td></td>
<td></td>
<td>que soy muy bueno en mi labor docente</td>
</tr>
<tr>
<td></td>
<td>Q9</td>
<td>I think I can properly teach even the most complex topics / Creo que</td>
</tr>
<tr>
<td></td>
<td></td>
<td>puedo enseñar de una manera adecuada incluso los temas más</td>
</tr>
<tr>
<td></td>
<td></td>
<td>complejos</td>
</tr>
<tr>
<td></td>
<td>Q10</td>
<td>I am unsure about my teaching performance / No estoy seguro de mi</td>
</tr>
<tr>
<td></td>
<td></td>
<td>buen desempeño como docente</td>
</tr>
</tbody>
</table>

Data Analysis

The preliminary validation of the instrument was conducted using Pearson correlation to explore convergent and discriminant validity across items and constructs (DeVellis, 2016). The interpretation of the Pearson correlation coefficient is as follows (Rubin, 2012): weak - 0.1 or lower; moderate - between 0.25 and 0.45; and strong - 0.5 or higher. Cronbach alpha was computed to evaluate internal consistency of each construct (Cortina, 1993), and
exploratory factor analysis was conducted to identify how these items measured the corresponding construct.

### Table 3: Items measuring relatedness for instructional design

<table>
<thead>
<tr>
<th>Variable</th>
<th>#</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relatedness</td>
<td>Q11</td>
<td>I feel supported to design my courses by other faculty members at my institution / Siento que tengo apoyo de otros docentes de la institución para el diseño de mis cursos</td>
</tr>
<tr>
<td>Relatedness</td>
<td>Q12</td>
<td>I am a part of a group of faculty members interested in instructional design / Hago parte de un grupo de docentes interesados en el diseño pedagógico de cursos</td>
</tr>
<tr>
<td>Relatedness</td>
<td>Q13</td>
<td>I can talk to other faculty members at my institution about instructional design / Puedo hablar con otros docentes de la institución sobre el diseño de cursos</td>
</tr>
<tr>
<td>Relatedness</td>
<td>Q14</td>
<td>I actually feel isolated in my teaching within the institution / En realidad, me siento aislado en mi labor docente dentro de la institución</td>
</tr>
<tr>
<td>Relatedness</td>
<td>Q15</td>
<td>I often feel alone when I am with my colleagues / A menudo me siento solo cuando estoy con mis colegas</td>
</tr>
</tbody>
</table>

### Findings

The data from participants’ responses to the pretest and the posttest were integrated to evaluate the validity of the instrument. A total of 90 answers to the survey instrument are included in this analysis. Table 4 depicts the Pearson’s correlations across items assessing autonomy, competence, and relatedness. The items in an orange shade (Q3, Q5, Q6, Q14, and Q15) did not show a strong relationship with the rest of the items, nor did it show the expected relationship.

The items Q1 and Q4 are strongly correlated, and Q4 showed a moderate correlation to Q2, suggesting that these three items are assessing the same construct: autonomy. The items Q7, Q8, Q9, and Q10 assess the perceived competence, and demonstrate convergent validity with strong correlation among them. Finally, the items Q11, Q12, y Q13 are correlated to each other, measuring relatedness in the context of course and instructional design. However, item Q11 (i.e., I feel supported to design my courses by other faculty members at my institution) is also moderately related to the items that measured competence (i.e., Q7, Q8, Q9, and Q10), which is a threat to discriminant validity. In general, each of the three constructs showed good internal consistency (Cronbach Alpha: Autonomy: 0.77, Competence: 0.82, Relatedness: 0.72) (Cortina, 1993), but additional data is required to strengthen this validation process.

The factor analysis confirmed the limitations of the instrument under the current sample. Table 5 shows the factor loadings and the Eigenvalues for the three factors. Using the varimax rotation method, the items explained 48% of the variation in the dataset. The construct for Autonomy seems to be measured by Q1, Q2, and Q4. However, the items measuring Relatedness do not satisfy discriminant validity with the construct of Competence and therefore, seem to be associated to factor one, particularly Q12 (i.e., factor loading of 0.56).
Table 4: Pearson’s Correlation Across Items

<table>
<thead>
<tr>
<th></th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
<th>Q6</th>
<th>Q7</th>
<th>Q8</th>
<th>Q9</th>
<th>Q10</th>
<th>Q11</th>
<th>Q12</th>
<th>Q13</th>
<th>Q14</th>
<th>Q15</th>
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<tbody>
<tr>
<td>Q1</td>
<td>1</td>
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<td></td>
<td></td>
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<td></td>
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<tr>
<td>Q2</td>
<td>0.59</td>
<td>1</td>
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</tr>
<tr>
<td>Q3</td>
<td></td>
<td>0.12</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Q4</td>
<td>0.57</td>
<td>0.4</td>
<td>-0.15</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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</tr>
<tr>
<td>Q5</td>
<td>-0.22</td>
<td>-0.28</td>
<td>0.1</td>
<td>-0.13</td>
<td>1</td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q6</td>
<td>-0.18</td>
<td>-0.23</td>
<td>-0.14</td>
<td>0.08</td>
<td>0.25</td>
<td>1</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Q7</td>
<td>0.35</td>
<td>0.53</td>
<td>0.32</td>
<td>0.27</td>
<td>-0.05</td>
<td>-0.37</td>
<td>1</td>
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<td></td>
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<td></td>
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<tr>
<td>Q8</td>
<td>0.25</td>
<td>0.41</td>
<td>0.22</td>
<td>0.19</td>
<td>-0.03</td>
<td>-0.2</td>
<td>0.47</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q9</td>
<td>0.3</td>
<td>0.38</td>
<td>0.37</td>
<td>0.24</td>
<td>-0.03</td>
<td>-0.25</td>
<td>0.63</td>
<td>0.61</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Q10</td>
<td>-0.17</td>
<td>-0.31</td>
<td>-0.22</td>
<td>-0.06</td>
<td>0.12</td>
<td>0.4</td>
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<td>1</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Q11</td>
<td>0.27</td>
<td>0.37</td>
<td>0.2</td>
<td>0.18</td>
<td>-0.1</td>
<td>-0.22</td>
<td>0.37</td>
<td>0.35</td>
<td>0.44</td>
<td>-0.35</td>
<td>1</td>
<td></td>
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</tr>
<tr>
<td>Q12</td>
<td>0.35</td>
<td>0.47</td>
<td>0.18</td>
<td>0.28</td>
<td>-0.1</td>
<td>-0.19</td>
<td>0.63</td>
<td>0.38</td>
<td>0.47</td>
<td>-0.33</td>
<td>0.49</td>
<td>1</td>
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<td></td>
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<tr>
<td>Q13</td>
<td>0.58</td>
<td>0.64</td>
<td>0.24</td>
<td>0.27</td>
<td>-0.22</td>
<td>-0.33</td>
<td>0.45</td>
<td>0.49</td>
<td>0.46</td>
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<td>0.5</td>
<td>0.4</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Q14</td>
<td>-0.13</td>
<td>-0.25</td>
<td>-0.2</td>
<td>0.13</td>
<td>0.16</td>
<td>0.35</td>
<td>-0.25</td>
<td>-0.23</td>
<td>-0.31</td>
<td>0.19</td>
<td>-0.34</td>
<td>-0.17</td>
<td>-0.3</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Q15</td>
<td>-0.21</td>
<td>-0.2</td>
<td>0.04</td>
<td>-0.02</td>
<td>0.41</td>
<td>0.26</td>
<td>-0.03</td>
<td>-0.2</td>
<td>-0.08</td>
<td>0.22</td>
<td>-0.19</td>
<td>-0.1</td>
<td>-0.29</td>
<td>0.44</td>
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Implications

One paramount goal of the assessment of professional development programs is to enable the designers to identify opportunities for improvement. However, this goal can be accomplished only when the data is accurate and reliable. The information collected through the instrument discussed in this paper will allow PDP designers to make well-informed decisions regarding the adjustments that can potentially benefit the participants.

Based on the results from this preliminary study, some of the items will be updated as follows for future iterations:

Autonomy
- Q3: External mandates often override my decisions for course design.
- Q5: I often need to include elements that I consider irrelevant into my course design.

Competence
- Q6: I am not sure what are the appropriate steps to design my courses

Relatedness
- Q14: I actually feel alone in the intention to improve my course design within the institution
- Q15: I often feel that I do not know who to ask for help to design my courses
Table 5: Item’s loadings from factor analysis

<table>
<thead>
<tr>
<th>Construct</th>
<th>Item</th>
<th>1</th>
<th>2</th>
<th>3</th>
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<tr>
<td>Autonomy</td>
<td>Q1</td>
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</tr>
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<td></td>
<td>Q2</td>
<td>0.38</td>
<td>0.62</td>
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<td></td>
<td>Q3</td>
<td>0.48</td>
<td>-0.12</td>
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<td></td>
<td>Q4</td>
<td>0.05</td>
<td>0.72</td>
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<tr>
<td></td>
<td>Q5</td>
<td>0.07</td>
<td>-0.21</td>
<td>0.48</td>
</tr>
<tr>
<td>Competence</td>
<td>Q6</td>
<td>-0.35</td>
<td>-0.01</td>
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<td></td>
<td>Q7</td>
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<td></td>
<td>Q8</td>
<td>0.65</td>
<td>0.19</td>
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<td></td>
<td>Q9</td>
<td>0.77</td>
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<td>Q10</td>
<td>-0.58</td>
<td>--0.06</td>
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<td>Relatedness</td>
<td>Q11</td>
<td>0.49</td>
<td>0.22</td>
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<td></td>
<td>Q12</td>
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<td></td>
<td>Q13</td>
<td>0.47</td>
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<td></td>
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<td>0.07</td>
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<tr>
<td></td>
<td>Q15</td>
<td>--0.03</td>
<td>--0.06</td>
<td>0.71</td>
</tr>
<tr>
<td>Eigenvalues</td>
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<td>3.27</td>
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<td>% of variance</td>
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<td>22%</td>
<td>15%</td>
<td>11%</td>
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</table>

Conclusions and Future Work

Transformative learning experiences are challenging to assess. Using language that is familiar to the participants from the beginning and connecting the items of a survey instrument to existing theories can support such an assessment process. The preliminary analysis of the survey instrument showed promising but limited validity. In particular, three items related to Autonomy showed convergent and discriminant validity. The items measuring Competence showed convergent validity but failed to discriminate from the items measuring Relatedness. Refining the items and increasing the sample size are the necessary steps forward. We only counted with 90 responses for this study, which became the main limitation of this study.

Next steps in the assessment of professional development programs include extending the instrument to consider changes in participants’ perspectives about teaching and connecting
them to the three variables assessed here: autonomy, competence, and relatedness. This is, exploring whether the faculty members experience any changes on how they see the role of the instructor, the content, the student, and the assessment of student learning.

**Acknowledgements**

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**References**


The role of mentors in navigating the paradoxes of industry-based learning

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Abstract: This paper explores the role of industry mentors in industry-based learning with the view to understanding their role in promoting efficacious workplace learning. The study used a qualitative methodology and drew on the experiences of thirty-four mechanical engineering students from a South African university of technology. Three paradoxes emerged from the data analysis: the paradox of learning through working, the paradox of access to meaningful work and guidance and the paradox of the mentor’s role as teacher and work supervisor. Recommendations are provided for the selection and training of industry mentors to try to ensure that they can navigate these paradoxes.

Introduction

There is growing realisation and acceptance that university-based activities alone are insufficient to prepare students for smooth entry into their selected occupations. Research provides two reasons for this deficiency. First, competent work performance requires use of procedural knowledge. Procedural knowledge refers to the knowledge that enables a person to know what to do in each situation as it arises (Pollock & Cruz, 1999). It is knowledge in action. Collins, Brown and Newman (1987) question whether classroom instruction is the only way to prepare learners to acquire this. They argue that while classroom teaching has been relatively successful in organising and conveying large bodies of propositional knowledge, it has not been as successful in imparting procedural knowledge. They further argue that classroom tasks, which are set in classroom environments, fail to provide the contextual features of authentic tasks. While this does not mean that classroom instruction is of little use, it signals that the context dependence of procedural knowledge and situatedness of learning cannot be ignored (Anderson, 1982; Anderson, Reder, & Simon, 1996). This does not mean that industry-based learning is sufficient on its own either. Illeris (2010) warns that education for the professions should not be left to industry since, if it were, the education would become narrow and short-sighted. Governments, universities and professional bodies agree that learning for the professions is best addressed by combining university-based learning with industry-based learning. Industry based learning (IBL) is a structured period of workplace-based learning in which students are attached to an occupationally relevant workplace for the students to gain relevant work experience as part of their qualification (Smith et al., 2009).

Second, as engineering education shifts towards training for current and future professional practice, it has become clear that some of the required competences cannot be developed through traditional instruction methods. Walther, Kellam, Sochacka and Radcliffe (2011), in writing about the developments in engineering education in Australia, Malaysia and the United States, discuss accidental competences (learning that is not a result of planned or formal instruction) and about how they are crucial for professional formation. They
conceptualised students’ professional formation as a complex interplay of technical and non-technical competencies that are developed through both formal instruction and exposure to work situations. One way of providing exposure to work situations is IBL. The incorporation of IBL as a formal part of university curricula is addressed by several related pedagogical practices, such as cooperative education in the United States and New Zealand, ‘sandwich’ programmes in the United Kingdom and vacation work and in-service training in South Africa. Recently, simulated exposure to work situations through work-directed theoretical learning, problem-based learning, project-based learning and simulated workplace learning have become acceptable as well. Pedagogical practices that provide actual or simulated exposure to work situations are grouped under the umbrella term work integrated learning (WIL).

The inclusion of IBL in the university curriculum often places competing demands on its role players due to differences in agendas of universities and of industry. The primary agenda of universities is education whereas that of industry is production efficiency and profit. These contradictory agendas can produce tensions in the roles of IBL stakeholders, particularly in the functioning of industry mentors, who are expected to simultaneously meet the needs of universities and those of their workplaces. In their study of clinical internships at the University of Leuven in Belgium, Deketelaere et al. (2006) found that competing demands between the mentor’s role as a coach and as an evaluator produced dynamic tensions between these roles. In addition, they found similar tensions arising from competing agendas of IBL as working and as learning. Similarly, in their study of teaching internships in the Gold Coast, Australia, Carpenter and Blance (2007), found tensions arising from competing demands of the practicum supervisor’s role as mentor and as evaluator.

Drawing on the perspectives of mechanical engineering students, this paper explores the contradictory demands of IBL and the tensions they produce in the functioning of industry mentors. In addition, it surfaces some of these contradictory demands as paradoxes. Lewis (2000, p. 760) defines a paradox as having “competing yet inter-related elements – elements that seem logical in isolation but absurd and irrational when appearing simultaneously”. Therefore, the paper seeks to answer two research questions: What are the paradoxes of IBL? And, how can industry mentors navigate these paradoxes to facilitate efficacious student learning? In answering these questions, the paper aims to contribute to better understanding of how to avoid the pitfalls presented by IBL paradoxes to promote effective and rewarding IBL experiences for mechanical engineering students.

Industry-based learning in South African engineering education

Engineering faculties of South African universities practise IBL differently. In many universities, IBL is offered as vacation work, which is non-credit bearing. For universities of technology, IBL generally takes the form of experiential training. Currently, universities of technology are in the process of phasing out their former national diplomas, which required 12 months of IBL. They are replacing them with new diplomas which include six months of WIL. The Engineering Council of South Africa (ECSA) accepts IBL, work-directed theoretical learning, problem-based learning, project-based learning and simulated workplace learning as meeting its requirements for WIL (ECSA, 2015). For universities, ECSA does not prescribe WIL for their engineering degrees.

Many positive outcomes of IBL for learners have been reported. These include increased employability, smoother university-to-work transitions, maturity, high occupational self-efficacy and career clarity (Brooks & Youngson, 2016). South African researchers claim that IBL provides structured pathway to employment ( Jacobs, 2015), which are particularly valuable for students from disadvantaged backgrounds who might not have social networks to exploit for employment (CHE, 2011). In spite of these positive outcomes, in South Africa, students wishing to undertake IBL face the challenges of access to IBL opportunities. Since the pool of companies that are willing to host IBL students is limited and university enrolments have been steadily increasing over the last two decades, there are not enough workplace learning opportunities to go around (Muterek o & Wedekind, 2015; Reinhard,
Pogrzeba, Townsend, & Pop, 2016). In addition, universities struggle to find appropriate host companies to provide students with meaningful and worthwhile IBL experiences. Peters, Sattler and Kelland (2014) warn that token placements, which are poorly structured or inadequately supervised, do more harm than good. Literature has shown that the cause of some of the above challenges is the absence of adequate mentoring during IBL and that industry mentors are crucial for proper structuring and adequate facilitation of IBL (Agwa-Ejon & Pradhan, 2017; Kramer-Simpson, 2018). Agwa-Ejon and Pradhan (2017), for example, report that their student participants indicated that they found their mentors’ guidance to be fundamental to successful IBL. Kramer-Simpson (2018) found that without the industry mentors’ provision of good student learning opportunities, IBL is inclined to be unsuccessful.

Research design

Mechanical engineering students from a South African university of technology, who were undergoing a twelve-month long IBL placement, were invited to participate in the study. From the responses, the researcher purposefully selected 34 students. The data collection and data analysis processes that were used are summarised in Figure 1.

![Figure 1: A schematic diagram outlining data collection and analysis steps](image_url)

The researcher collected qualitative data from the participants using semi-structured interviews. The interviews were conducted in the latter half of their placement periods. Each interview lasted between 23 and 57 minutes. Prior to the interviews, field observations were conducted at the participants’ host companies to broaden the researcher’s understanding of
their IBL contexts. Data analysis started with an a priori list of codes from the pilot phase (this is reported in an earlier paper). As shown in Figure 1, the data analysis followed a six-step thematic analysis process that was developed by Bryman (2012). The data analysis was conducted with the assistance of NVivo which was especially useful for data display, diagramming and case comparisons. It must be noted that the researcher obtained ethics approval from the relevant universities to conduct the study.

Presentation of findings

Analysis of the qualitative data revealed that several factors influenced student learning during IBL. Among them, the role of the mentor was found to be most significant. To the students, the industry mentors' actions were the most significant expression of their workplace environments. This was because the mentors allocated work to them and facilitated their participation within the workplace communities. In reviewing codes related to mentoring functions (Analysis Stage 6 in Figure 1), it became clear that the mentors were attempting to navigate through the following three paradoxes:

The paradox of learning through working

There were tensions between the university and industry about how IBL should happen. On the one hand, according to the IBL learning manual provided by the university, the purpose of IBL was the integration of theory and practice, implying structured learning. In other words, the university expected industry to supply and structure work participation for theory and practice integration rather than just providing work experience. On the other hand, the industry role players assumed that the purpose of IBL was exposure to work situations for the students to gain work experience, implying incidental learning.

From the company’s perspective, operations within the workplace are directed towards maximising value for their shareholders. Hence, they focus on production efficiency. At times, this focus overlapped with the university’s expectations. In such cases, the functioning of mentors proceeded unhindered or was actively supported by the host companies. However, in instances when operational-level interests and IBL’s interests diverged, the work environments became unresponsive to the students’ learning needs. This tension between production efficiency and learning needs sometimes appeared to the students as if their mentors did not care about their learning. For example, Student 20 complained:

> The only thing they care about is production, their production. They don't really care about us. It's like they don't know why we are there. For them, it's just for us to be exposed to industry. I think they think that we are there for money (Student 20).

Given student complaints like the one above, it would be expected that the students would have been satisfied with structured learning. However, the students who undertook their IBL at the university’s workshop, which had more structure, were also dissatisfied because they thought the experience was not authentic enough. For example, Student 19 complained about the lack of work pressure and deadlines:

> I have been working here, it is an institution, it is a company, but obviously, the work environment is a lot less structured. I would say it is a lot less formal. Whereas in an actual company, you have your deadlines and things, you have the structure and you have to make sure that you meet those deadlines (Student 19).

Analysis of the data showed that neither structured learning nor incidental learning was adequate. Effective IBL required both. This is because the students needed to be guided until they have mastered performing meaningful work. This was a challenge because most industry mentors were supervisors and managers whose primary responsibility was production efficiency. When they accepted to mentor the IBL students, they added secondary
responsibility of facilitating student learning. This did not require them to provide separate working tasks but rather to afford the IBL students opportunities to participate in work activities with minimal disruption to the production efficiency agenda. Student participation in work activities was key to authenticity and meaningfulness of the IBL experiences. Absence of these two attributes produced IBL experiences that students considered token and unauthentic.

**The paradox of access to meaningful work and to guidance**

According to the students, efficacious learning required both access to guidance and access to meaningful work. However, the capacity to provide these two essential elements of effective IBL did not usually reside in the same individual except in exceptional circumstances. This capacity was characterised by two attributes of mentors: mentor capacity and mentor availability. Mentor capacity was related to their ability to provide their protégés with meaningful work, to facilitate their participation in the workplace communities and to protect them from adverse effects of work errors. In most cases, high-capacity mentors, who were mostly from the upper levels of the host companies, were able to provide all the above mentoring functions, including providing their students with meaningful work. Sometimes, they even diverted work from other staff or assigned their own projects to their students. For example, Student 32 spoke of how his mentor diverted work from their City X office to their City Y office to expose him to a variety of tasks.

> All the drafting used to be done in City X because the company head office is based there. Nevertheless, currently my boss [and mentor] diverts everything to me, so I am the one that is currently doing all the drafting (Student 32).

However, the problem with high capacity mentors was that they were often unavailable to attend to their students’ day-to-day needs. For example, Student 2 narrated his experience with his initial mentor who was his host company’s General Manager (GM):

> It started out as the GM of the company, but the GM was often away and too busy for us (Student 2).

The high capacity mentors’ unavailability undermined students’ access to guidance. Mentor availability was related to the ease with which students could access mentor support. IBL students needed guidance on what to do, what to observe from their co-workers and how to participate in work activities. The students needed this type of guidance because the most meaningful work activities that they were exposed to were too complex for them to complete them on their own and because of the ambiguity of their roles within the workplaces. They needed guidance and support in a similar manner to the instructional scaffolding in the zone of proximal development described by Vygotsky (1978). High availability mentors, who were often the students’ immediate supervisors, were readily available to provide guidance. For example, Student 24 explained how he benefited from having his supervisor as his mentor.

> If I struggled with something, I would go to him [my mentor], we would work together…. if I get stuck, like everyone else, I go and tell my supervisor and he shows me the way he does things (Student 24).

However, these mentors often did not have the authority to assign students to other departments even when they thought the students would benefit from such an arrangement. As a result, their students were often exposed only to a narrow scope of work. For instance, in the above case of Student 24, he worked solely in the maintenance department while his sponsoring company had several other mechanical engineering-inclined departments. Another student, Student 17, mentioned how she worked only in the tooling and machining workshops that her mentor was responsible for despite her host company having several other workshops and laboratories.

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I spent 12 months of my life in that workshop with my mentor. Therefore, I am only comfortable in what he knows – the two areas. I never got a chance to go into the strength labs, the thermodynamics or the metallurgy labs (Student 17).

Because high capacity mentors were often constrained close guidance, they only did so when their interests aligned with those of the university (focus on student learning). This was case with Student 1 whose father was the owner/manager of his host company. It was in the interest of Student 1’s father to provide him with both meaningful work and with guidance:

He shows me that if this happens, you have to do this and that. He gives me the basic knowledge. If I struggle with something, I have a fellow worker behind me, I ask him. I also go directly to him and he helps me.

It was not only family relationship which caused alignment of mentor and university’s interests, some mentors were motivated by their own earlier experiences as IBL students. In cases where they were unavailable fulfil both functions, these mentors were able to compensate for their unavailability by delegating some of their mentoring responsibilities to their subordinates.

The paradox of the mentor’s role as teacher and work supervisor

Most participants spoke of their mentors either as if they were teachers or merely supervisors. These two positions reflect the tension that exist between learning and working, which also presented itself in mentor-student interactions. When mentors presented themselves as teachers, they prioritised student learning over operational gains or, at least, considered them together. In contrast, when mentors positioned themselves as supervisors, they prioritised productivity over learning. Such mentors directed their efforts to ensuring that the students became productive as quickly as possible. Once the students had attained acceptable work proficiency, these mentors made sure that they met some operational demand such as replacing staff who had resigned or filling positions that had arisen due to increased work demands. For example, Student 16 believed that economic pressures at his sponsoring company forced it to ignore his learning needs:

The company knows what we are supposed to be doing because their Operations Manager is a former University X’s mechanical student. Therefore, he knows what students are supposed to be doing there. However, it has more to do with economics for them because when it is a busy time, they have to take in temporary workers. They pay them more money compared to the stipends they are giving students who are actually doing the same job as those people. Therefore, they are winning by taking students (Student 16).

In contrast, the analysis indicated that mentors-as-teachers recognised that their mentees were still students and as such, would often make mistakes. Furthermore, they were aware that if their mentees were to learn from their mistakes, they needed to protect them from the negative consequences of work errors. In this study, the students who considered themselves to have had adequate placement experiences often moved on from sections of the workplace in which they had become competent to other sections in order to develop their skills further or to learn new skills. This meant continued work errors as part of the learning process. Student 31 narrated the learning potential of work errors and how his mentors allowed him to grow from them:

Initially, I made many mistakes: not understanding speeds and feeds of drills and cutters, not setting out my work correctly. Therefore, with that, a few cutters were damaged. A few drills were also damaged and so on. Not accurately measuring work pieces. For instance, when I had a spare to
make, and if the dimensions and the pitches of the positions of the rows were not accurately measured, then the whole component would be wrong. They received it well because they understood where I am coming from; I am new in the environment. They tolerated my mistakes. They gave me leeway to make mistakes, and to grow from my mistakes (Student 31).

Mentor roles were not static; they were responsive to the prevailing environments within the workplaces. In some cases, changes in workplace conditions influenced changes in mentor positions. In this study, the most common change in workplace conditions was staff shortages due to resignations. For example, Student 19’s mentor seemed to change his role from mentor-as-teacher to mentor-as-supervisor when one of his welding assistants resigned. He then appointed the student as a welding assistant to replace him. As a result, the student’s experience shifted from adequate to inadequate. She narrated the change:

> What happened was that one of the staff members had left and he needed someone to fill his position. Therefore, [the mentor] approached me and asked whether I could fill in…. I actually had a job description, my job was a lab assistant, and that is what I did…. Because of my job description being a lab assistant, I never had the opportunity to work on a CNC machine and the plasma cutter (Student 19).

The two mentor roles often appeared to be simultaneous opposites. However, the findings showed that for effective learning, industry mentors needed to concurrently meet the demands of both roles by operating as both teachers and supervisors. When they did this, the mentors were able to provide authenticity and structure, the two ingredients required for rich workplace learning. Some mentors resolved this challenge of occupying paradoxical roles by sequencing. They first assigned tasks to students as they did with any other employee and only providing guidance and protection as required by the student. Student 26 recounted how this arrangement worked in his case:

> When he first sent me to supervise, it was very difficult for me. The challenge was that I was supervising people who were more knowledgeable about the job than I was. Therefore, when they came to me and told me they had a problem, I had no idea what to do. The job was delayed because I did not actually know the job. Therefore, I went and reported this to him, and I went back to the people with him. He then told me that this is what you must look for especially on bending. He helped me, but it took me two more weeks to master supervising these people (Student 26).

It emerged that experienced mentors managed this paradox better than new mentors. For example, Student 8 summed up why he thought his mentor knew and anticipated his learning needs:

> My mentor and director was very accustomed to training students so he knew exactly what to give me at a certain point in time. If any specific design required knowledge that he needed to check if I had, he would ask me and we would talk about it. So, when I was given something to do, I knew exactly what to draw on (Student 8).

Balancing between the two roles required a heuristic approach that experienced mentors were more likely to have mastered. They drew from their experiences of mentoring previous students or/and their own earlier experiences as IBL students to find the balance between teaching and supervising. According to the students, balance between these two aspects led to productive relationships between students and their mentors.
Discussion

This study’s findings show that for effective learning, industry mentors need to be able to navigate the three paradoxes inherent in IBL. IBL role-players should, ideally, avoid simple either/or choices that exacerbate the negative consequences that arise from satisfying one of the competing demands at expense of the other. For instance, IBL was unsuccessful when the university attempted to recreate itself within workplaces by enforcing too much structure to the IBL. This shows that universities should appreciate the uniqueness of learning within workplaces and its resulting ambiguities rather than seeking to eliminate its paradoxical tensions. Although the two paradoxical demands arising from learning and working appear as contradictory, successful IBL requires that they be viewed as interdependent and capable of co-existing. Universities need to take a similar stance in choosing industry mentors. Similarly, mentor capacity and mentor availability should be seen as complementary and interdependent. Therefore, industry mentors need to be trained to accept, cope with and accommodate the tensions arising in their competing roles as teachers and as work supervisors.

If competing demands are paradoxes, eliminating one of them does not address the underlying tension. Lewis (2000: 763) note that this “actors’ defensive behaviours initially produce positive effects but eventually foster opposite, unintended consequences that intensify the underlying tension”. There is evidence of this defensive behaviour in the rationale that some South African faculties of engineering have provided for their shift from IBL to other forms of WIL. They sought to eliminate the industry agenda in their students’ exposure to professional practice. Although the fact that students benefit from IBL is hardly in dispute, these universities have expressed doubts about the effectiveness of IBL as a mechanism for assisting students in acquiring practical engineering knowledge. For universities, IBL is viewed more as a learning intervention, a means of integrating theory and practice and is viewed less as working for the purpose of enhancing student work readiness. The universities’ doubts about the effectiveness of IBL are reinforced by the fact that most engineering companies perform specialised work, making it difficult for them to provide IBL experiences with sufficient integration of theory with practice other than limited propositional knowledge that is relevant to their speciality. However, if IBL were seen as preparing students for work, encompassing both theory-and-practice integration and promotion of work readiness, then the reality of co-existing paradoxical demands becomes acceptable. It must be noted that since IBL for engineering students is based in private companies, its intrinsic paradoxes are more pronounced and more difficult to resolve. In addition, industry mentors are more prone to specific company pressures. Therefore, they should be assisted in better managing IBL’s inherent paradoxes if IBL is to be an effective way of enhancing students’ employability.

This paper extends the work of IBL researchers Deketelaere, Kelchtermans, Struyf and De Leyn (2006) and Carpenter and Blance (2007). Although these researchers have found IBL to be rife with competing demands, they did not identify them as paradoxes. As a result, they suggested an either/or approach to managing the resulting tensions. This paper identifies IBL’s competing demands as paradoxes. This is significant as it signals that management of their resulting tensions cannot be by an either/or approach (Lewis 2000). It allows their management to be reframed to avoid IBL role players’ actions that might perpetuate and exacerbate the paradoxical tensions. This can be done by adopting an and/both approach to managing the paradoxes (Smith, Lewis, Jarzabkowski, & Langley, 2017).

This paper positions industry mentors as IBL stakeholders that are better placed to manage these paradoxes. This positioning of the industry mentors is consistent with that of Agwa-Ejon and Pradhan (2017) and Kramer-Simpson (2018) who also situate them as the critical determinants of IBL success. Agwa-Ejon and Pradhan (2017) propose that, to ensure effectiveness of IBL, industry mentors need to be trained to prepare them for their roles. This paper extends this proposal and advocates that mentor training should include how to implement structured learning within workplaces. This would assist mentors to navigate...
through the paradoxes identified in this paper. The paper further proposes that industry mentors be selected by universities based on their positions within their organisations’ hierarchy since those on a higher level are able to allocate meaningful work to the student while resolving their availability challenges.

Conclusion

Inspection of engineering education literature shows that there is a growing realisation and acceptance that university-based activities must be supplemented with industry-based learning in order to sufficiently prepare students for smooth entry into their selected occupations. However, learning in the workplaces is challenging due to its paradoxical nature. Its inherent paradoxes have limited its application in engineering education. This paper used a qualitative multi-case study of thirty-four mechanical engineering students from a South African university of technology to explore how industry mentors are perceived to navigate through the inherent paradoxes of IBL to ensure its effectiveness.

After a six-step thematic analysis, three paradoxes that are inherent in IBL emerged. The first paradox, learning through working, relates to the differences in the agenda between universities, which prefer structured learning and industry, which offer incidental learning. The second paradox, access to meaningful work and to guidance, arose because capacity to provide meaningful work and guidance does not often reside in the same individuals. High capacity mentors, who were mostly from the upper ranks of the host companies, were able to provide meaningful work but struggled with being available to their students. On the other hand, high availability mentors, who were mostly from the lower levels of the host companies, were readily available to provide guidance but often did not have the authority to allocate work to the students. The last paradox relates to the role of the mentor. When mentors positioned themselves as supervisors, their actions were directed at either ensuring that the students became productive as quickly as possible or ensuring that the students fulfilled certain operational needs. In contrast, when mentors positioned themselves as teachers, they prioritised students’ learning over operational gains or at least considered them together. It emerged from the findings that both of these industry mentors’ roles are required for efficacious student learning.

In most cases, industry mentors served as interfaces between the IBL students and their broader work environment. As a result, their actions and roles were significant to student learning. Therefore, this paper proposes that initiatives that seek to improve the efficacy of IBL should focus on assisting industry mentors on how they can effectively manage the challenges arising from the paradoxical nature of IBL. These initiatives should strive to enhance the industry mentors’ ability to operate as both teachers and supervisors. This would enable them to structure student learning in a manner that meets the requirements of industry, incidental learning through exposure to authentic practice, without compromising the benefits that accrue from having a structured path of gaining occupational competency. It is clear from this that industry mentors need training if they are to efficaciously fulfil their obligations as envisaged by IBL role-players.

References


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Engineering teachers becoming action researchers through a community of practice at an alternative school for “Street Youth” in western Kenya

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Abstract: Estimates of “street youth” (SY, children who work/sleep on the streets) in Kenya are over 300,000. Engineering Education presents a unique opportunity to realize the potential of this population to develop 21st-century skills. However, teachers at alternative schools for “street youth” are untrained in STEM education, and the issue is exacerbated by the shortage of qualified teachers in sub-Saharan Africa. We have pioneered an approach in preparing teachers to facilitate engineering programs at an alternative school for SY in Kenya via an engineering Community of Practice (CoP). In this work-in-progress study, the teachers use action research to improve their practice and learn to do research. We investigate how action research informs teachers’ development in a CoP.

Introduction
Sandra, Ellie, and William (pseudonyms) are three untrained engineering teachers at an alternative school for “street youth” (SY, children who work/sleep on the streets; Steffen, 2012) in Western Kenya who advocate for their students and facilitate introductory engineering courses. The alternative school, initially started as a drop-in centre for street children, transformed into an innovation centre hosting and educating SY in primary and vocational education. The primary education teachers, who formed the majority of the teaching staff until the end of 2018, had limited or no experience in teaching Science, Technology, Engineering, and Mathematics (STEM) subjects. Having taken part in the co-facilitation of the inaugural engineering-based curriculum, the teachers reported that engineering, in fact, plays a significant role in the development of skilled citizens, and they were interested in learning more. The curriculum was designed and delivered by engineering education researchers from Purdue university in the United States. The teachers took part in professional development opportunities that used the model of reflective practice, which then organically resulted in the formation of a Community of Practice (CoP).
In this work-in-progress study, we present the next step in professional development undertaken by the teachers to learn and apply action research. While becoming reflective practitioners, the teachers started developing stronger relationships with their teaching practice, their peers, and the discipline of engineering. Upon identifying these relationships, we hypothesized that they could be strengthened by training teachers as researchers. Action research studies have shown that the ability to research in respective teaching environments leads to continuous development in self-understanding of the practice, the discipline, and the “own-selves”, which is critical to sustaining the development efforts meaningfully (Goodnough, 2010). In this study, we describe the rationale of using action research in a teacher community-of-practice and identify the changing relationship of teachers with their practice, peers, and discipline.

**Engineering education for street youth in K-12 classrooms**

SY are difficult to support in traditional formal schools due to transcience and stigma, and they face enormous challenges developing the 21st-century skills needed to enter the workforce. However, informal learning spaces that empower youth to solve problems themselves may provide them with the knowledge and skills that they are shut out from in formal schools. Engineering is uniquely positioned to aid in the development of employable skills. Miaoulis (2010) argued for integrating engineering into K-12 curriculum, justifying that the current science curriculum covers less than 5% of our day-to-day activities, ignoring the other 95% of the human-made world (mainly focusing on technology). According to him, “engineering promotes problem-solving and project-based learning, makes mathematics and science relevant to students, offers a wide range of high-paying career choices, and helps all students better navigate a three-dimensional world.” (p.21). Other arguments for the integration of engineering into K-12 settings have related engineers’ focus on providing real-world context for learning mathematics and science, developing problem-solving skills, promoting development of communication skills and teamwork, giving fun and hands-on settings, and most importantly, preparing youth for 21st century problems and more authentic STEM contexts (Moore et al., 2014).

In the context of our study, Kenya is facing an employment crisis due to the mismatch between workforce demands and education (Wasunna, 2018). Kenya’s recent curriculum reform calls for building seven core competencies in K-12 learners: communication and collaboration, self-efficacy, critical thinking and problem solving, creativity and imagination, citizenship, digital literacy, and learning to learn (Kenyan Institute of Curriculum Development, 2017). Research suggests that engineering builds most of these seven core competencies in K-12 learners (Masek & Yamin, 2011). Therefore, we have pioneered an approach to unlocking SY students’ capacity to engineer at an alternative residential school called Tumaini Innovation Centre (TIC) in Western Kenya. TIC currently hosts students between 11-18 years in primary and between 18-30 in their vocational programs.

Our student-led, integrated engineering curriculum uses problem-based learning to teach design, STEM fundamentals, evidence-based decision making, entrepreneurship, and professional skills (communication and teamwork) around an authentic local challenge. In April 2018, students completed the first module, culminating in the design and installation of a solar photovoltaic system to light the school’s classrooms. In the on-going second module, the students have identified issues in the areas of energy, transportation, and agriculture. Our prior research has shown that co-designing an engineering course with students and teachers can catalyze learner engagement, meaning, and agency and lead to sophisticated, engineering products (Radhakrishnan & DeBoer, 2016). Additionally, our work also showed that students identify their teachers as role models who play a critical role in the success of each student (Radhakrishnan, DeBoer, & Kimani, 2018). The teachers who understand the complex needs of SY, however, lack formal training in STEM education and, for some, formal qualifications in primary school teaching.
Engineering teachers’ professional development

Our engineering curriculum is situated around three specific content areas. As a community-centered problem-solving curriculum, the engineering design process is the main content area and the connecting thread for all other content. The engineering design process is integrated with the technical content (e.g., electronics like Arduino, sensors, 3D-modelling) and professional competence content. The curriculum uses active learning (Felder & Brent, 2009) techniques such as hands-on activities, problem-solving tasks, blended learning (Means, Toyama, Murphy, & Baki, 2013) tools like the tablet and laptop technology with both online and face-to-face modes, and collaborative learning (Dillenbourg, 1999) via team-based activities. Research conducted to understand the experiences of the students in this engineering curriculum revealed that the SY learners find the ABC framework to be motivating and meeting their educational needs (Radhakrishnan & DeBoer, 2016). However, the challenges identified included the teachers’ struggle to internalize a challenging and complex curriculum with many moving parts and in an advanced topic like engineering. Several studies of engineering education in the K-12 space in the United States have identified related challenges with respect to teacher preparation, including a lack of engineering concepts in teacher preparation programs, attitudinal biases, existing structure of K-12 curriculum, complexity of content area, limited real-world problem-solving experiences, and lack of pedagogical content knowledge (Hynes & Dos Santos, 2007; Nadelson et al., 2013; Wang, Moore, Roehrig, & Park, 2011; Zarske, Yowell, Sullivan, & Carlson, 2004). Therefore, professional development for teachers in engineering is required to address these challenges and improve teachers’ confidence in their ability to implement an engineering curriculum (Jonassen, Strobel, & Lee, 2006). Realizing the need for teacher capacity development in engineering, training sessions involving teachers in the engineering design process were organized to improve their content knowledge. The teacher training needed to be continuous (see, for example, Jovanova-Mitkovska, 2010) to ensure the sustainable development of pedagogy, content, and technological knowledge and use in classrooms. The training initially focused on reflective practice.

Preparing teachers to be reflective practitioners has gained wide acceptance, increasingly being adopted as the standard in many countries for professional competence (see, for example, Hatton & Smith, 1995; Jay, 2003; Larrivee, 2000; Osterman & Kottkamp, 2004). Smyth (1989) suggested that even novice teachers can deepen their level of reflection with powerful facilitation and mediation within an emotionally supportive learning climate. There is an emerging consensus that pre-service and novice teachers can be helped to reflect at higher levels with multifaceted and strategically constructed interventions (see, for example, Cole & Knowles, 2000). In 2018, at the alternative school, a continuing professional development model was designed using the framework of reflective practice. The three teachers used reflections to plan, act, and observe their class sessions. By engaging in reflective practice over six months, the teachers learned to function as a collaborative team, improved their teaching practice, made meaning of their engagement, and developed an engineering identity. As the next step in professional development, the teachers and researchers agreed that developing their skills as researchers could strengthen their role as engineering teachers. In this work-in-progress study, the teachers use action research to improve their practice and learn to do research. We investigate: (1) How does conducting action research inform the teachers’ development of knowledge and skills on the practice of teaching, on teamwork with their peers, and on the domain of engineering? (2) How do the teachers describe the growth of their knowledge and skills of research in addition to teaching, teamwork, and engineering?

Action research for teacher development

Many approaches to teacher professional development have emerged. Those currently being adopted range from short-day training sessions to longitudinal growth via teacher inquiry (Loucks-Horsley, 1996). Action research as another approach has longstanding roots in the
field of teacher development. Teacher action research systematizes the process of development through habits of reflection about one’s teaching and a sense of heightened awareness of their practices and of what was happening in their classrooms (Zeichner & Noffke, 2001). Smith and Fernie (2010) argued that all teachers could use the action research method to continually improve the effectiveness of their teaching. Preisman (2007), a teacher educator, wrote about her experience seeing that action research is significant in teachers’ lives, describing action research as meaningful, friendly, and possible. Virkki-Hatakka et al. (2013) concluded from their study on developing chemical engineering course methods that action research-based improvement processes contributed useful courses, successful learning, and professional skills of the teacher. Capobianco and Ni Riordáin (2015), working with preservice science and mathematics teachers, suggested that the action research approach taken by the teachers provided valuable opportunities to improve their practice, their understanding of their practice, and the situation in which their practice takes place. All three components of development are necessary for our context as the teachers develop a new field of knowledge and practice outside of their expertise that is contextualized to the community being served. The authors studied uncertainties faced by teachers during their learning and saw that not only did the teachers face challenges in learning to teach science and mathematics, but also in conducting action research. However, with time, action research assisted in recognizing, accepting, and addressing the uncertainties positively and productively.

Theoretical Framework: Community of Practice

The initial professional development using reflective practice (Schön, 1987), evolved into the formation of a CoP, allowing for the teachers (second, third, and fourth authors) and the researcher (first author) to deepen their knowledge in the area of teaching engineering. Therefore, for this study, we adopt the CoP as our theoretical framework. The notion of CoP is used as an entry point into a broader theory of learning that has several constituent components (Wenger, 1998). In the more comprehensive social theory of learning, four elements are integrated—meaning (learning as experience), practice (learning as doing), community (learning as belonging), and identity (learning as becoming)—to “characterize social participation as a process of learning and of knowing” (p. 5). These four elements provide a guideline in evaluating the learning of teachers through the lens of legitimate peripheral participation, where learning is identified as a contextual social phenomenon, achieved through the participation in a Community of Practice (Floding & Swier, 2012).

CoP, then, are “groups of people who share a concern, a set of problems, or a passion about a topic, and who deepen their knowledge and expertise in this area by interacting on an ongoing basis” (Wenger, McDermott, & Snyder, 2002, p.4). Many CoP’s have existed within the context of education and have adopted action research as a strategy for fostering teacher learning in many domains, such as subject matter knowledge, knowledge of pedagogy, and knowledge of classroom practice (Briscoe & Wells, 2002; Gayford, 2002; Goodnough, 2001).

Context: Teacher Participants

The three teachers in the study are Ellie, Sandra, and William (pseudonyms). Ellie and Sandra joined as course instructors six months into the start of the curriculum. William initially took a secondary role as a course instructor. The lead instructor appointed initially for this course resigned from TIC after four months. Ellie, Sandra, and William became lead teachers based on increased student enrolment at the centre. During this study, the course was conducted on multiple days of the week, and, therefore, the three teachers shared primary responsibilities and split their schedules.

Among the three teachers, Ellie is the only one who had a formal background in education, even she had no prior teaching experience. Ellie, when she started to work at Tumaini, initiated and continues to teach literacy courses (English and Kiswahili) for all grades of students. Ellie was appointed as the head teacher in 2017. Ellie became the primary engineering instructor
for nine new students who came into the centre in 2017. This group of students was referred to as the junior class. Sandra joined Tumaini as an intern and was inducted as a full-time employee in the year 2017. Sandra also serve as the human resource manager, fundraising coordinator, accountant, and farm manager at Tumaini. She instructs classes on engineering for both junior and senior classes. William started as a volunteer teacher and social worker for Tumaini. He was promoted to a full-time social worker and teacher in 2017. During this study, William taught science, social studies, and engineering classes. He collaborated with Sandra on planning and instructing the engineering classes for the senior students.

Research design, methods, and procedures
The work-in-progress study is situated within a two-year long Design-Based Research (DBR) project. DBR is a methodological approach created by learning scientists in which researchers investigate solutions to educational problems by designing interventions and iteratively testing them in real-world practice to see how they function in formal or informal educational settings (Barab & Squire, 2004; Fishman, Penuel, Allen, Cheng, & Sabelli, 2013). DBR was generated from the need for a research methodology that closely linked and directly applied research into ongoing, situated educational practice. DBR was selected as an appropriate methodology for this study for several reasons. First, the very nature of DBR as a set of processes to develop research-based solutions for complex problems in educational practice (Plomp, 2013) guides the sustainable development of this project. Second is the case of DBR as a much-needed strategy in engineering education, where “it has the potential to develop change agents who are familiar with the context, culture, the subject area, and new teaching and learning methods, and who have the ability to facilitate the transformation of practice in collaboration with local academic staff” (Kolmos, 2015, p.373). Third, DBR is designed to form design principles as one of the expected outcomes. This study will evaluate the applicability of action research as a strategy for untrained teachers’ professional development in engineering and generate knowledge to form the final design principles. In this current study, DBR has guided in the design of applying action research as a follow-up strategy to reflective practice from the first-phase of our DBR.

Status of teacher action research projects
The three teachers are in the process of conducting their first action research cycle. The teachers are each at different stages of the research process. All three of them have identified their research areas of interest and framed their respective research questions as the following: collaborative learning, active learning, and community engagement. They have also completed a preliminary literature review. The status of each teacher is given below. Sandra: conducting research on understanding perceptions of engagement between the local community and the school through the engineering classes, with both the students and community members. She has conducted a literature review, identified data sources, finished data collection and is currently performing a first round of analysis. Ellie: conducting research on ways to achieve full participation of all student team members in engineering classes. She has completed a preliminary literature review and identified data sources and is currently in the process of data collection. William: conducting research on identifying and understanding the effectiveness of different active learning techniques for teaching science content in engineering classes. He is in the process of identifying active learning strategies to implement in his classroom and is also in the process of finding relevant data collection instruments.

Data Collection
The study began with a follow-up workshop to the previous research on reflective practice. The kick-off workshop assisted in the formation of the community of practice, setting up the expectation, guidelines, and the central theme for this collaborative group. The first author introduced the teachers to the model of the action research cycle (Carr & Kemmis, 2003) and discussed potential strategies that are relevant to the context and the CoP. A variety of data collection sources allowed us to gather extensive qualitative data and provided opportunities
through guided and unguided reflection. Journals: Notebooks were intended to provoke reflection on the teachers’ experiences before, during, and after class sessions. The teachers used the double entry (Feldman et al., 2013, pp.24) format of reflection for their pre- and post-class reflections. A total of 3 journal entries were completed by each teacher for a total of 9 journal entries. Interviews: Individual semi-structured interviews (approx. 30 min.) were conducted with two teachers (Sandra and Ellie). Due to logistical challenges, William’s interview is yet to happen. Therefore, the analysis and results focus on Sandra and Ellie for this work-in-progress. The interviews gathered more information about the teachers’ experiences with teaching engineering, their experiences building a CoP, and their experience with research so far.

Data analysis
Data were analysed using thematic analysis. Braun and Clarke (2006) define thematic analysis as “a method for identifying, analysing, and reporting patterns (themes) within data” (p.79). At each stage of analysis, the data were coded using the following process. First, in the process of “open coding,” a code was assigned to a unit of analysis defined as a word, phrase, or sentence (Saldaña, 2015). For example, when teachers discussed the practices and frameworks around teaching, these statements were coded as TCHN PRAC or “teaching practice”. Another example was when the teachers described events when learning about research, these events were coded as “LEARN RES” or “Learning research”. These codes were then read, re-read, and grouped into common categories using the four aspects of “meaning”, “practice”, “community”, and “identity” as discussed in the CoP. These were later merged to interpret preliminary findings.

Results and discussion
In answering research question 1, we discuss the preliminary results for teachers’ relationships based on their growing comfort and/or discomfort with the three areas of learning development teaching practice, community, and the discipline of engineering.

Teaching practice – Attitude reinforcement and growing expertise
Since the point of beginning to conduct the action research, teachers’ attitudes towards teaching have been positively reinforced and is being considered as an expertise that they are continuing to master. Ellie, as a formally trained teacher, reflected on and understood her strengthening love for teaching. The positive reinforcement of her teaching practice occurred as she continued to gain a better understanding of her teaching through reflection and knowing that her teaching had a positive impact on students.

“In the last three months, some factors have made me improve in teaching. First, I think accepting and having a positive mind that I can teach, mainly engineering. Then loving what I do has participated a lot in my teaching because I always love what I do to make it easier for me. So, it used to be a little bit difficult for me to do it because I was not so sure if I want to do it and again I wasn’t so sure if I’m doing the right thing. But since I get to know what I’m doing is right and benefiting students and other people are learning from me and I have people who are depending on me to teach them that, I developed an extra ordinary interest.” (Ellie, Interview, 2019)

Sandra described herself as feeling like an expert on teaching after reconfiguring her perception of teaching. Sandra’s knowledge of teaching was limited due to her professional training as an economist. However, as she took up the task of teaching the engineering classes and participated in the CoP, she changed her prior conception of the field.

“I feel like an expert. I love explaining something to someone, but I didn’t used to love teaching. It was quite different. I love sitting and exchanging ideas with people and seeing how we can work something out rather than standing in front of people who are just listening to me and teaching. Having now to know that it’s okay to just even sit with the students and just talk as a way of teaching and getting to hear their ideas and everything. I think it made me more open to teaching.” (Sandra, Interview, 2019)
Sandra and Ellie’s quotes demonstrate their increasing comfort with the practice of teaching, largely with respect to teaching engineering, during their engagement in the professional development sessions. This finding extends one from prior research on this case as they engaged in reflective practice, where reflections fostered their practice of teaching. Continuing on professional development with action research is starting to show higher potential for growth in their teaching practice.

Community – Mutually beneficial yet challenging to fully “belong”

Community (according to Wenger (1998), “learning as belonging”) of peers has been a complex relationship. Both Sandra and Ellie discussed being part of the community as mutually beneficial for the individual and the group. However, it also had challenges.

For Sandra, the community is challenging particularly when collaborating in teaching due to her personal preferences.

“Having this community, you know, in a way it has been challenging, reason being I love doing things in a team but not teaching. First, I didn’t think it was even possible. But challenging in a good way to getting out of my comfort zone. I prefer doing things on my own, I have a certain way I do things, and to me it’s a mindset that I have, and I like controlling my environment very well. So, when you bring in other people and you have to be accountable to them, and they have to be accountable to you, it was something I’m not used to…”

However, she continued to describe how the community has been beneficial to each other, in the ways of sharing knowledge, skills, and resources.

“… but it challenged me also to get out of my comfort zone and then I saw the need of us working together. And us working together actually helped me. Because I’m not a teacher, Ellie is. There are some few things I’ve learned from Ellie. Again, I’m not a social worker, so I do not really understand the boys as well as William does. And now working, collaborating with all of them, gives me now the skills of a teacher and a social worker. I know how to manage the class and I know what to do when this happens, or what to expect.”

Ellie’s description resonated with that of Sandra’s, noting the community collaborations as being challenging while also being beneficial. While the benefits mentioned by Sandra and Ellie were almost the same, Ellie’s description of challenges was different. Ellie felt the other team members possessing other primary responsibilities (outside of teaching), made it difficult to think as a community.

“I’m working with people from different departments and they have different schedule. So most of the time, I sometimes I feel like I need to do this as a team with them but they’re not available, sometimes due to avoidable circumstances maybe our social worker is not around, maybe our HR is handling somethings in the office, maybe you, you (first author – researcher) are busy doing other things. So, experience of community… I think I’ll say it’s ‘ish’ ‘ish’, it’s 50 50, sometimes it gets so good, sometimes not.”

The challenges as described by the teachers need to be considered with some contextual factors. During the past three months, multiple development projects at the centre caused Sandra and William to be less visible in teaching, as seen in Ellie’s description. Before these three months, the teachers identified their community as extremely resourceful, while also the place they generated meaning about their practice.

Engineering – “is experience” (provides meaning)

For the teachers, engineering is a developing identity as they continue to learn through experience and apply engineering knowledge to their situations. Sandra described that, to her, engineering meant experience.
“engineering is not just knowing but experiencing it. It's until I ... Before, I used to hear about engineering, of course, having done physics in high school because I couldn't do biological, because I hated biology. It was again another topic you just do to pass the exams, So, you just have the knowledge of how things work and everything, but no it is actually living it out. Because, well, for you to solve a problem right now, for me, I see you have to actually feel the effect of the problem for you to really want to solve it. Many people don't see the problem probably because it doesn't affect them. But now for me, engineering is that experience. Like you have to experience what is happening for you to actually do something about it.”

As the teachers continue to facilitate the engineering curriculum via the problem-based learning model, their understanding of engineering has been situated in the idea of problem-solving. Here, Sandra's description of engineering demonstrates self-generated meaning on the field of knowledge she has continued to learn through the strategies of reflective practice and action research.

**Research - Distant cousin/source of power**

Referring back to the status of action research projects, both Ellie and Sandra are at different stages. The second research question aims to understand how the teachers situate research in relation to the three components of professional development, i.e., teaching practice, collaborating in a community, and the discipline of engineering. As the study is still in its earlier stages, it is not possible to draw any definitive conclusion on this yet. However, during the interviews the teachers explained how they view and experience research.

Ellie, still in the earlier stages of the research, found research to be challenging, although she was still positively motivated to learn and apply it. Metaphorically, describing research to be her “distant cousin”, Ellie mentioned she got some satisfaction with her developing identity as a researcher when she was able to perform a task specific to research.

“Research so far, I think we are distant cousins, we were about to be good sisters and brothers but now we are cousins. I write everyday about research in my journal because I want to learn more about it. It's just in my heart that I want to do it and I also want to do it for the sake of others, for the sake of myself and for the sake of the whole community, so, yeah. When I went on and interviewed some people last week I felt like 'ah' I can be a researcher and I was so serious I'm like asking them questions, trying to listen to them. I'm also trying to be a good listener because a researcher also needs to be a very good listener.”

Sandra, being in an advanced stage of finishing the first cycle of action research, viewed research as information that is a source of power. At this stage, Sandra’s description of research, in addition to giving more information, is connected to change or knowledge of what to do next. It is well-situated in the ideology of action research, which looks at a change as the outcome of research (Elliot, 1991).

“Research to me now is information, and Information is power. There's little that you can do about something you know nothing about. Chances are we see a problem with electricity, but because you don't know why there's no electricity or why there's a shortage in supply around this community or even at my place, well, it doesn't bother me. It's very easy for me to just point a finger and say, "The Kenya Power is not working." Or, "The ELDOVAS, for the water is not so efficient. But when you get to learn about that challenge, get to see even how it has affected others, then you get to have even a broader view. And out of that, information that you get, you're able even to know what you should do next.”

Research is a complex task that integrates multi-disciplinary skills and takes years of practice to master it. Etherington (2004) in his book, “Becoming reflexive researchers” wrote, “even mature academic researchers complain about the dearth of information about the process of becoming a researcher and the many aspects of life that this journey touches” (p.15). Three months is a short time for these teachers to gain understanding on the full scope of a
research process, yet the teachers are demonstrating changing perceptions and comfort in developing the skillset.

**Conclusion**

In this work-in-progress study, we have presented a detailed account of our approach and rationale in using action research to develop informally trained engineering teachers' capacity. Our results are limited as a work-in-progress, since the full scope of the study is not complete and must be whole in order to draw more definitive conclusions. The teachers at the alternative school for SY have undertaken action research to research their teaching environments to build capacity in teaching engineering and conducting research. In this ongoing study, we have identified the teachers' developing relationships across four components: their teaching practice, their community of peers, the discipline of engineering, and the task of research. Our preliminary analysis has shown that the teachers are developing a stronger relationship with the practice of teaching and the field of engineering. However, the peer community and research continue to pose challenges for some teachers. The teachers continue to demonstrate positive motivation to overcome the difficulties and develop meaningful learning experience with both those components as well. Upon completion, results from this study will yield in-depth understanding of the complex interplay of learning development of untrained teachers as engineering facilitators and teacher-researchers.

**References**


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Diversity in groups – students’ reflection

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Abstract: Rapid changes in the South-African society demand from students to function in a complicated and diverse society. Cognisance of the unique context South-African students must be more prepared for a complicated workplace and therefore need to be exposed to diverse settings during their studies. Diversity develops students' cognitive growth and exposes them to the intricacy thereof. Students enrolled in the Community-based Project Module, an undergraduate module of the Faculty of Engineering, Built Environment and Information technology at the University of Pretoria are encouraged to create diverse groups for their community project. The study aims to reflect on students' perceptions of their exposure to diverse groups. The results of a survey were qualitatively coded and categorised for themes. Students reflected that diverse groups gave them the opportunity to solve problems using different points of view. The students found it an enriching experience to interact off campus with students from different courses, races and gender. The feedback received from students’ reflections after completing the module indicates personal growth and stronger cognisance of the challenges of the diverse South African society as a common theme. The study confirms the value in preparing the future workforce in South-Africa to value diversity as an asset and recommends the inclusion of diversity as a soft-skills attribute in the curriculum of undergraduate engineering students.

Introduction

In the South African society race has become the basis for post-apartheid redress. Subsequently, demands the workplace from employees to be skilled in inter-cultural communication competencies and to function within a diverse society. Diversity within the South African community gives engineering students the opportunity to work in a dynamic environment with people from different backgrounds and genders. For this reason, is it vital for Higher Education Institutions (HEI’s) to encourage and foster diversity as an attribute for students to function in a context which prepares them to be locally and globally employable. The Engineering Council of South Africa (ECSA) exit level outcome 8 also requires students to “Demonstrate competence to work effectively as an individual, in teams and in multidisciplinary environments” (ECSA 2014, 6). It creates an integration-and-learning perspective and a psychological safe microenvironment of the broader society. Diversity has an impact on the performance when the task is complex as well as non-routine (Summers & Volet, 2008).

This study aims to evaluate the value of group diversity as a criterion for group formation and to develop insight into students' perception of the impact of diversity within their service learning groups. The service learning module replicates an elementary work environment and the student's views, and challenge students to engage with the possible issues they may experience in a diverse group in the work environment.

Service learning

Through a service-learning module, students have the opportunities to be challenged on their previous experiences, and their perceptions of the world or existing prejudices (Eyler & Giles
Jr, 1999; Furco & Root, 2010). A student-centred approach through authentic learning (Dewey, 1938) are integrated into a structured service-learning endeavour. Subsequently, provide a service learning course with an experience outside of the traditional educational environment and facilitate authentic learning in a rich and unique context. Students have the opportunity to gain new knowledge through problem-based and active learning (Spronken-Smith, 2012).

The Faculty of Engineering, Built Environment and Information Technology at the University of Pretoria in South Africa integrated a compulsory free-standing module, Community-based Project Module (course code: JCP) in the curriculum of all undergraduates. This service learning module primary objectives include a positive influence on a relevant section of society by exposing students in groups to real-life challenges. Subsequently, students could become more aware of their social responsibility. Social awareness is created when students apply existing or newly acquired knowledge for the betterment of the community by illustrating their understanding of the social issues relevant to the project. Students must learn to function collaboratively in a multidisciplinary and multilingual environment applying various life skills such as communication-, interpersonal-, technological- and leadership skills. Through their projects, the students must become aware of- and cultivate personal, social and cultural values (Martina Jordaan, 2014).

The course must be completed within the allocated 80 notional hours. Students do at least 40 hours of fieldwork and after that reflect on their experiences through various reflective assignments on the e-learning management system as well as a final presentation, reflective video and report. More than 1600 students have annually registered with a 95% average completion rate. The students worked per annum on average in 500 groups with more than 370 different campus-community partners. Implementing these considerable number of projects successfully, requires a unique teaching and assessment model, sustainable community partnerships, robust logistical and financial processes, effective communication and passionate administrative management- and academic staff (M. Jordaan, 2013).

Depending on the logistics of the project students may divide themselves into groups of two and five students. Some students execute their projects in neighbouring countries which makes the logistics of a large group difficult. The module has specific criteria that a project must adhere to. Projects may not promote religion or political party or receive any reimbursement while they are working on the projects. The projects must, for example, be executed at pre-schools, schools, non-profit organisations, museums or on campus. The community partner and the students must identify a specific task that must be complete in the academic year for the project within the allocated hours. The supervisor on site assess the students and logs their hours. It is therefore essential that students work closely with a supervisor on site. For two-thirds of the 2018 cohort (2018:66,14%), their JCP community service module was their first structured community outreach experience.

The diversity of the selected projects for the 2018 group are illustrated in Figure 1.
From the 441 registered groups, 93% of the groups (411 groups) including 1404 students completed the module. The high success rate of the module in 2018 is aligned with previous years success rates. The drop in groups is due to groups that either merged to create a larger group of students that discontinued their studies. The most popular projects for 2018 were renovation projects (41.4%) and well as teaching Mathematics and Science for secondary school learners (17%). Students also preferred projects related to animals, for instance, animal shelters, animal sanctuaries or zoo’s (11.7%). Diversity in choices of projects available contributes to the success of the students as their own choice implies willingness and commitment to a specific challenge in the community selected.

Theoretical framework

Typically diversity refers to the perceptions that certain characteristics of another person are different from oneself (Baker, Saifuddin, & Stites-Doe, 2018). Surface and deep-level diversity are the two theoretical perspectives that are integrated into diversity studies (Harrison & Klein, 2007). Surface-level diversity is defined as the difference between group members that are obvious like biological characteristics, for instance, race and gender and age (Harrison, Price, & Bell, 1998). However, surface-level diversity, influence possible forming of closer relationships as it creates an immediate sense of dissimilarity amongst group members (Cunningham & Sagas, 2004) and will probably hinder social interaction and communication (Mohammed & Angell, 2004).

Cognitive abilities, attitudes, skills values and attitudes are associated with deep-level diversity and are linked to psychological characteristics of individuals (Harrison & Klein, 2007). Group members require clues from each other as well as time to become aware of the deep-level diversity in the group. Deep-level diversity, therefore, manifests more frequently in longitudinal group projects. Subsequently, will cognitively diverse teams be more advanced and prepared to be innovative in constructively solve the challenge at hand (Garcia Martinez, Zouaghi, & Garcia Marco, 2017).

Constructivism, as a learning theory for Community-based project module, provides the theoretical foundation to understand the process students apply to construct knowledge, and apply a new synthesis to the challenges in the communities (Fenzel & Peyrot, 2005). To understand what is required in the learning tasks and to achieve the outcomes students must actively use prior knowledge and strategies while group members and community partners contribute to the application of the knowledge that developed from shared meanings and experiences (St George, 2008). Consequently, is the hypotheses investigated in this paper...
that group diversity will increase the construction of new knowledge through access to a range of different perspective on the best solution to address the community need.

**Diversity within the module**

The compositional diversity of the University through race and gender provides students in the module the opportunity to work in diverse groups. Also, it gives the number of degrees students are enrolled in the opportunity to work in groups which include different subject domains in the Faculty. The compositional diversity of courses in the module include three different schools. The school for engineering combines ten degrees, while the school for built environment integrates six degrees. The third school, the school for information technology, presents nine different degrees courses. Figure 2 illustrates the percentage compositional diversity of race and gender of the 2018 group.

![Figure 2: Compositional percentage gender and race diversity within the module](image)

White male students (39.2%) still dominate the compositional gender in the module during 2018. There was an increase of African male (23.8%), white female (13.3%) and African female students (13.2%) in contrasts to previous years. The increase in female and African students enabled groups to be more race and gender diverse. Students are encouraged to compile diverse groups of race, gender and courses (M Jordaan & Maharaj, 2018). Figure 3 indicates the ratio of the diversity and combination of criteria of the groups for 2018.
Figure 3: The percentage criteria or combination of criteria of the diversity of the 2018 groups

The highest percentage of students prefer to create diverse groups of gender and degree diversity (23%). To create groups that were diverse in race, gender and degree (9%) were logistically challenging for the students (M Jordaan & Maharaj, 2018).

**Problem statement**

The primary aim of this research is to identify common themes from the students’ reflections to determine what the educational benefit is of diverse groups within a service learning module and to what extent the integration of diversity as a group structure criteria impacted surface or deep-level diversity in the groups.

**Methodology and procedure**

After completing their projects, students were requested to reflect on their experiences in their diverse groups. Of the 1404 students that completed the module 251 students (17.88%) completed the survey about diversity in the groups. The survey included three questions and was administered using Qualtrics software (Qualtrics Labs, Provo, UT). The students who completed the survey indicated that the majority (75%) of the groups were course (75%) gender (86.84%) diverse while 38 % included race-diversity (35.75%).

All the data were qualitatively coded and categorised for themes. After a cross-link comparison, all the data were examined for patterns and themes. The data were qualitatively analysed separately but were added to the final step of identifying the analytical themes and patterns.

**Results**

Table 1 provides a summary of the perceived added value for students of diverse groups in a service learning module.
Table 1: Reflections on the value of the diverse group

<table>
<thead>
<tr>
<th>Theme</th>
<th>Subtheme</th>
<th>Example of feedback of students</th>
<th>Number of responses (N=251)</th>
<th>% of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Deep-level diversity</td>
<td>Cognitive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Different knowledge</td>
<td>“The knowledge base was also much wider since we study different modules.”</td>
<td>15</td>
<td>6%</td>
</tr>
<tr>
<td></td>
<td>Different approaches</td>
<td>“A diverse group means a diversity of ideas and approaches to challenges.”</td>
<td>5</td>
<td>2%</td>
</tr>
<tr>
<td></td>
<td>Different skills</td>
<td>“You learn to get along with a different type of people thus allowing you to get those skills for the future in the workplace.”</td>
<td>64</td>
<td>25.5%</td>
</tr>
<tr>
<td></td>
<td>Different perspectives</td>
<td>“We could see things in different perspectives.”</td>
<td>59</td>
<td>23.5%</td>
</tr>
<tr>
<td></td>
<td>Different viewpoints</td>
<td>“There were different views and opinions on how to go about completing tasks.”</td>
<td>31</td>
<td>12.4%</td>
</tr>
<tr>
<td></td>
<td>Different thinking patterns</td>
<td>“Learned about different ways of thinking as well as how to work with people who think differently to you.”</td>
<td>21</td>
<td>8.4%</td>
</tr>
<tr>
<td></td>
<td>Different ideas</td>
<td>“To make use of different skills and ideas from different perspectives.”</td>
<td>17</td>
<td>6.8%</td>
</tr>
<tr>
<td></td>
<td>Different opinions</td>
<td>“Getting different opinions and looking at a task from a different perspective.”</td>
<td>15</td>
<td>6%</td>
</tr>
<tr>
<td>Soft skills</td>
<td>Communication</td>
<td>“It was very interesting to have a diverse group because every day during the project we had the opportunity to communicate and to learn about our differences. Our group was more prolific as we were a good combination and always had a combination of varies ideas given the varies aspects and experiences we have. We always helped each other.”</td>
<td>8</td>
<td>3.2%</td>
</tr>
<tr>
<td></td>
<td>Teamwork</td>
<td>“Learning a lot from people from different cultures and different study fields was exciting. A diverse group of people can bring a diverse range of opinions to the”</td>
<td>3</td>
<td>1.2%</td>
</tr>
</tbody>
</table>
Most of the students reflected on the value of deep-level diversity within their group. The cognitive difference in their group that added value to the group different skills (25.5%), perspectives (23.5%), viewpoints (12.4%), thinking patterns (8.4%), ideas (6.8%), knowledge and opinions (6%) and approaches (2%). The compositional diversity of courses in the module group may influence this reflection. Fewer students reflected on the added value of soft skills, for instance, communication skills (3.2%) and teamwork (1.2%) of diverse groups. Surface diversity, for example, the value of different genders in the group (11.2%) were also identified as an added value of diverse groups.

The students were also requested to reflect on the challenges to be part of a diverse group. Table 2 summarises the issues that the students reflected on what they experienced negatively in a diverse group.

Table 2: Reflections on the challenges experienced to be part of a diverse group

<table>
<thead>
<tr>
<th>Themes</th>
<th>Example of feedback from students</th>
<th>Number of responses (N=251)</th>
<th>% of responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultural</td>
<td>“Learning from people from different cultures.”</td>
<td>43</td>
<td>17.1%</td>
</tr>
<tr>
<td>Different</td>
<td>“It allowed us to understand each other different backgrounds more and be more aware.”</td>
<td>23</td>
<td>9.2%</td>
</tr>
<tr>
<td>Accommodate</td>
<td>“Helped with recognising differences between people and acknowledges that these differences are a valued asset.”</td>
<td>4</td>
<td>1.6%</td>
</tr>
<tr>
<td>Gender issues</td>
<td>Working with different genders</td>
<td>28</td>
<td>11.2%</td>
</tr>
<tr>
<td>Social</td>
<td>“We made new friends for life.”</td>
<td>18</td>
<td>7.2%</td>
</tr>
<tr>
<td>None</td>
<td></td>
<td>16</td>
<td>6.4%</td>
</tr>
</tbody>
</table>
Deep-level diversity

<table>
<thead>
<tr>
<th>Cognitive differences</th>
<th>“Conflict because of differences in thinking patterns.”</th>
<th>2</th>
<th>0.8%</th>
</tr>
</thead>
</table>

Surface diversity

<table>
<thead>
<tr>
<th>Culture and religion</th>
<th>“There are possible culture/religious clashes.”</th>
<th>2</th>
<th>0.8%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>“The males always felt superior over the females; in other words, they always wanted to have the last say.”</td>
<td>4</td>
<td>1.6%</td>
</tr>
</tbody>
</table>

None

| None | 34 | 13.6% |

Fewer students reflected on negative issues in a diverse group. The highest percentage (86.5%) of students did not give any feedback on the question. The students (13.6%) that did respond to this question indicated they did not experience any issues about diversity in their groups. Diversity issues that were identified were surface diversity of gender (1.6%) and culture and religion (0.8%). Only two students (0.8%) identified deep diversity issues of cognitive difference (0.8%).

Conclusion

A large number of students did not have the opportunity to work in a group before enrolling in the JCP-module. The students have the choice to work in their self-created groups where they could work in diverse groups of race and gender but also diverse courses. It gave students the freedom to decide how much they what to be exposed by diversity within their groups. Students that reflected afterwards about their experience in diverse groups indicated that deep diversity issues were of value for their personal development. The negative issues that students identified diverse groups were more focused on surface diversity.

Being in a diverse group’s students had the opportunity to be exposed by their peers with different backgrounds thereby making them ready for the work environment. Through the experience, students will become effective and participating members of society. The data indicate deep-level diversity had a higher impact on the student’s community experience than surface level diversity and provided evidence to continue to use diversity as a criterion for group structures.

References


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Short-term international service-learning: engineering students’ reflections on their learning experiences

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Abstract: Short-term international service-learning experiences offer a global understanding to students who would not be exposed to community challenges in another context. Consequently, it is an opportunity for internationalising higher education. An opportunity was created for students enrolled in the Community-based Project (JCP) module at the University of Pretoria to engage with international students in the implementation of their community project. The JCP module is a compulsory module for all undergraduates of the Faculty of Engineering, Built Environment and Information Technology at the University of Pretoria. Five second-year engineering students from Wu Yuzhang Honor College of the Sichuan University and one student from Hong Kong Poly University helped students from the University of Pretoria to complete their 40 hours of fieldwork. The aim was to increase the students’ global awareness, build intercultural understanding, and enhance civic mindedness and skills. The study shows that short international exchange programmes can positively influence students.

Introduction

The workplace requires employees who are skilled in intercultural communication competencies. It has become crucial for higher education institutions (HEIs) to encourage and foster internationalisation and globalisation (Sowa, 2002). Globalisation requires world citizens to understand and acquire global communication skills. A global citizen is expected to understand foreign languages, political and socio-economic structures, and the cultural and artistic traditions that are the foundation of the thoughts and behaviours of their international colleagues (Carlson, Burn, & Yachimowicz, 1990; Lai, 2018).

One method of developing the interdependence of nations and creating international citizens is to develop short student exchange programmes (Sowa, 2002). It can be beneficial for the institution and have educational benefits for the students (Holman, 2001), as illustrated by the study of Vikström, Kamwesiga, Mubangizi, and Guidetti (2017). The authors indicate that a student’s interaction with international students has a beneficial effect on their learning and professional identity. Such experiences have the potential to shape students’ beliefs about their ability to create positive social change in communities. It influences how students perceive and interact with communities from marginalised groups. Such experiences also
influence the student’s willingness to continue to participate in community engagement projects (Rubio, 2018).

A well-designed student exchange programme can expose students to an authentic cultural environment and develop competencies that cannot be replicated in the traditional classroom. The study of Kraft, Ballantine, and Garvey (1994) investigates three models for student exchange: total immersion, protective studies and touring (Neppel, 2005). HEIs benefit from these exchange programmes through student recruitment, the contribution of their alumni and faculty development (Holman, 2001; Johnson, Johnson-Pynn, & Pynn, 2007). Unfortunately, student exchanges can be expensive, as students may have to pay for personal expenses, travel and housing (Sowa, 2002).

It is vital for today’s mobile workforce to be able to study abroad. Students involved in an international study may find it easier to be part of international projects that require them to alter their expectations, reduce ethnocentrism and prejudice, and assist them in understanding the significance of foreign language study (Goldstein & Kim, 2006). Through exchange programmes, such as international service-learning programmes, students may help to improve the lives of the citizens of the visited country (Arum & Van de Water, 1992). These programmes often increase students’ desire to go abroad for extended periods (Christie & Ragans, 1999).

Through the incorporation of short-term study experiences in service-learning modules, students have the opportunity to become more aware of different cultures and come to appreciate diversity (Zamastil-Vondrova, 2005). Colleges and universities usually offer exchange programmes that are shorter than eight weeks (Donnelly-Smith, 2009; McGuinness, O’Connell, & Kelly, 2014) to overcome the acknowledged challenges of longer exchange programmes. The duration of service-learning projects allows the successful integration of short-term international exchange projects.

**Service-learning**

Service-learning provides authentic and often complex opportunities for students to challenge their prejudices, previous experiences and perceptions about the world (Eyler & Giles Jr, 1999; Furco & Root, 2010). Service-learning integrates various pedagogical philosophies. These philosophies focus on student-centred approaches and support the concepts of authentic learning (Dewey, 1938), as they make provision for authentic experiences that provide a learning opportunity outside the traditional educational environment. Service-learning focuses on student-centred approaches as it links problem-based learning, project-based learning, active learning, collaborative learning, inquiry-based teaching and discovery learning (Spronken-Smith, 2012).

The Faculty of Engineering, Built Environment and Information Technology at the University of Pretoria in South Africa presents a compulsory, free-standing module, the JCP module, into its undergraduate study programmes. This service-learning module’s primary objectives include having a beneficial impact on a relevant section of society by exposing groups of students to real-life problems. Subsequently, students get the opportunity to become more aware of their social responsibility. Students must learn to work collaboratively in a multidisciplinary and multilingual environment by applying various life skills such as communication, interpersonal, technological and leadership skills. Through their projects, students must become aware of and cultivate personal, social and cultural values (Jordaan, 2014).

The course must be completed within the allocated 80 notional hours. Students do at least 40 hours of fieldwork, after which they reflect on their experiences through various
assignments, including a final presentation, reflective video and report. Since 2011, more than 1 600 students have registered for the module annually with an average completion rate of 95%. Each year, the students work in approximately 500 groups with more than 370 different campus-community partners. Successfully implementing this considerable number of projects, including humanitarian engineering projects, requires a unique teaching and assessment model, sustainable campus-community partnerships, robust logistical and financial processes, effective communication, and passionate administrative management and academic staff (Jordaan, 2013).

Theoretical framework

Constructive learning theory is the module’s theoretical foundation. Service-learning allows students to construct knowledge and develop a new synthesis of the communities’ challenges when their beliefs are questioned by what they observe during their engagement projects (Fenzel & Peyrot, 2005). Students actively use prior knowledge and strategies to understand what is required in the learning tasks to achieve learning goals and to monitor and regulate their learning. The module encompasses the co-construction theory, in which the community partners, lecturer, team members and community members use their knowledge to contribute to the development of shared meetings (St George, 2008).

The service-learning module

The module’s success has created opportunities for students enrolled in the JCP module to engage with international students in the implementation of their community project. Previously, JCP students had the opportunity to network with students from the University of Radboud in The Netherlands and the Massachusetts Institute of Technology (MIT) in the USA. During 2016 and 2017, a group of second-year engineering students from the University of Illinois Urbana-Champaign in the USA helped the JCP students to complete their fieldwork. It was a positive experience for the JCP students, who would otherwise not have had the opportunity to work with students from another country during their undergraduate studies.

The JCP module lecturer invited students to South Africa through the University Social Responsibility Network. Five second-year engineering students from Wu Yuzhang Honor College of the Sichuan University, China, and one student from Hong Kong Poly University accepted the invitation to help the JCP students complete their 40 hours of fieldwork. The 2018 student exchange programme aimed to increase the students’ global awareness, build intercultural understanding and enhance civic mindedness and skills.

The visiting students had to pay for their airline tickets, but the programmes at Sichuan University and Hong Kong Poly University that allow students to visit other countries assisted with the cost of the airline tickets. The visiting students had the opportunity to experience a specific section of the community, and total immersion was achieved by living with host families in the South African community.

The programme lasted one week. The visiting students attended a one-day orientation session before they started their community project with the JCP students. The orientation session included a campus tour, and briefs on the dynamics of South Africa, the module and its outcomes, and safety aspects. The orientation day gave the JCP students a chance to complete their project planning and make the final logistical arrangements.

The students were allocated to different JCP groups. One student worked with a group that had to design and develop a small mammal enclosure that a local zoo could use to transport animals. Two students assisted with renovation projects at two different animal shelters and another three students assisted with computer laboratory maintenance at a secondary school in a neighbouring township.
Problem statement

The primary aim of this research was to use the students’ reflection to determine the educational benefit of the short-term international service-learning for both the hosting and the visiting students. The secondary aim of the research was to inform other short-term service-learning exchange projects and allow similar exchange projects to note the pragmatic implications of such a project.

Methodology and procedure

Online pre- and post-project surveys were administered to the visiting and hosting students. The reflection strategies included written and oral feedback. The reflection allowed the students to synthesise what they had learnt or read about the culture of the participating international students and what they had experienced.

The pre- and post-project surveys were emailed to all the students. The pre-project survey consisted of seven items and the post-project survey comprised five items. The surveys were administered using Qualtrics software. Of the 19 South African students involved in the project, four (21%) completed the pre-project survey and 10 (52%) completed the post-project survey. Four of the six Chinese students (67%) completed the pre-project survey, and all six of the Chinese students completed the post-project survey. All the South African students presented their final project by means of a PowerPoint presentation, a YouTube video and a written report. During the presentation, the students verbally reflected on their experiences. These reflections were transcribed. The Chinese students were asked to email a reflective essay to the course coordinator.

All the data were qualitatively coded and categorised according to themes, after which the researchers removed any statement that did not conform. They also identified themes in the collection. All the data were examined for patterns and themes after a cross-link comparison was done. The data was separately analysed qualitatively and added to the final step of identifying the analytical themes and patterns.

Results

The results were divided into four categories: the students’ expectations, challenges they anticipated, problems they experienced and lessons they had learnt from the project. The students also provided practical suggestions to improve similar projects in the future. Table 1 summarises the students’ expectations.

<table>
<thead>
<tr>
<th>Subtheme</th>
<th>Example of the South African students’ feedback</th>
<th>Number of responses (N = 6)</th>
<th>Example of Chinese students’ feedback</th>
<th>Number of responses (N = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Creating new relationships</td>
<td>“I expect them to not only have fun and learn about our country but also to build a relationship with fellow students and enjoy the community project.”</td>
<td>4</td>
<td>“I expect to build friendships with local students.”</td>
<td>4</td>
</tr>
</tbody>
</table>

Table 1: Students’ expectations
Cultural exchange

“I expect to learn about their heritage and culture.”

4

“It sounds interesting to be in South Africa. I want to explore different things.”

3

Unsure

“I am not sure what to expect.”

2

The JCP students and the Chinese visitors were positive about the visit. In their final presentations, all the JCP students indicated that they had opted to be part of the project so that they could get to know the Chinese culture better and establish a link with students from another country. It sounded “cool” and “exciting” to them. The Chinese students indicated that they wanted to build new friendships and learn more about South Africa. Contrary to the positive comments, both groups of students highlighted the practical challenges that they experienced. Table 2 summarises the difficulties the students encountered.

Table 2: The challenges the students experienced

<table>
<thead>
<tr>
<th>Subtheme</th>
<th>Example of the South African students’ feedback</th>
<th>Number of responses (N = 6)</th>
<th>Example of the Chinese students’ feedback</th>
<th>Number of responses (N = 4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>“The language barrier was a challenge. We struggled to understand each other completely, and the context of what we were saying was often misunderstood.”</td>
<td>6</td>
<td>“I cannot communicate well with my poor English.”</td>
<td>3</td>
</tr>
<tr>
<td>Safety</td>
<td></td>
<td></td>
<td>Safety problems</td>
<td>4</td>
</tr>
<tr>
<td>Cultural understanding</td>
<td>“The international students do not fully understand the problems our society faces, and they do not respect our cultural differences.”</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Teamwork</td>
<td>“They felt like they were not part of the group.”</td>
<td>2</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Before the project, all the South African students and three of the Chinese students (75%) were worried about the language barrier. The impact of international perceptions of safety in South Africa was visible in the safety concerns of the Chinese students. To address this concern, the visiting students attended a safety lecture that was presented by one of the University’s campus security staff members. The South African students were made aware of the fact that the Chinese students’ safety was of the utmost importance.
Both groups’ feedback illustrated the alignment of the results between the pre- and post-project feedback. Table 3 shows this alignment.

Table 3: The problems the students experienced during the project

<table>
<thead>
<tr>
<th>Subtheme</th>
<th>Example of the South African students’ feedback</th>
<th>Number of responses (N = 10)</th>
<th>Example of the Chinese students’ feedback</th>
<th>Number of responses (N = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language barriers</td>
<td>“I would say the most difficult thing would be the language barrier, even though I felt like we could have worked around it to work well together.”</td>
<td>9</td>
<td>“Speaking English was a challenge.”</td>
<td>6</td>
</tr>
<tr>
<td>Expectations were not achieved</td>
<td>“Get them involved in the planning phase.”</td>
<td>2</td>
<td>“My teacher told me that an engineer was needed to do this project, but I found that anyone can handle the job I did.”</td>
<td>2</td>
</tr>
</tbody>
</table>

After the project, nearly all the students (both South African and Chinese) indicated that the language barrier was the most problematic issue to be overcome. One Chinese student had high expectations of an intensive engineering task that he would execute and was disappointed with the identified project.

The lessons learnt from the project, as summarised in Table 3, show the different interpretations of the value of the service-learning projects.

Table 4: Lessons learnt from this project

<table>
<thead>
<tr>
<th>Subtheme</th>
<th>Example of the South African students’ feedback</th>
<th>Number of responses (N = 10)</th>
<th>Example of the Chinese students’ feedback</th>
<th>Number of responses (N = 6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Work ethics</td>
<td>“I have learnt that Chinese students have a much better work ethic than we do.”</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cultural differences</td>
<td>“I learnt how to work with people from other cultures.”</td>
<td>10</td>
<td>“I was completely immersed in a foreign family. I lived in an unfamiliar, all-English, environment.”</td>
<td>1</td>
</tr>
</tbody>
</table>
Proceedings of the Eighth Research in Engineering Education Symposium
Cape Town 10–12 July, 2019: Peer-reviewed Full Papers

<table>
<thead>
<tr>
<th>Basic skills</th>
<th>“I learnt how to paint.”</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language development</td>
<td>“Language barriers were a problem, but we could overcome this challenge.”</td>
<td>8</td>
</tr>
<tr>
<td>Civic development</td>
<td>“I realised that I could make an impact on the community.”</td>
<td>5</td>
</tr>
</tbody>
</table>

The lessons the students learnt confirmed that they had acquired the required global skills, as identified by Turner and Robson (2008). During the South African students’ reflections, the students praised the Chinese students’ work ethics. The South African students reflected on the social responsibility and soft skills they had acquired during the project. The Chinese students commented on the skills they had acquired. Their focused task orientation is verified by the study of Li, Guo, Yao, Wang, and Yan (2016), which indicated that Chinese students strive to regulate their cognitive strategies and behaviour to serve their recipients during the process of service-learning. Chinese students might put a high value on their academic gain, but the JCP students fully understood the importance of their contribution to the wider South African society.

At the end of the project, the Chinese students gave the project an average rating of 85% and gave working on the project a score of 86%. The students gave higher ratings to accommodation (95%), food (91%), working with the JCP students (94%) and the excursion organised by the JCP students (94%).

All the respondents indicated that the language barrier was one of the most critical challenges they faced during the project. During the presentation session, this issue was mentioned in all the South African students’ presentations. Even though the Chinese students also indicated that they struggled to communicate, their written feedback was of an extremely high standard.

The South African and the Chinese students reflected that it was important for the visitors to be involved in the planning process of the exchange programme and its projects. Through the group presentations, it was evident that some students continued to maintain contact with each other after the exchange project. One of the groups organised for the Chinese students to participate in their final project presentation via Skype.

Conclusion

The short exchange project gave 19 students enrolled in the JCP module a unique experience that other academic modules could not. These students perceived the benefits of the added value they gained from the short exchange project. The students often expressed themselves differently, but everyone focused on similar themes. Irrespective of the few students involved, the feedback received and the Chinese students’ willingness to participate in the final project presentation in the early hours of the morning illustrated the value of this international service-learning experience.

The students reported that international service experiences serve a unique purpose in their learning and development. The data shows that, even though it is a short experience, the students viewed it as eye-opening and it gave them the opportunity to understand each other’s culture and way of thinking. The students learnt to work with and to interact with
people of different cultures and obtained the requisite skills to function in a global arena because of their short-term service-learning experience.

Discussion

Through the experience with other universities, the course coordinator realised that it was vital to invite students in the same year of study and following the same course to participate in the project. Students must be made aware of the module’s context and its anticipated outcome. The visiting students reflected that it is crucial to involve the visitors from the start of the project. They felt alienated from the project and saw themselves merely as labourers who had been appointed to complete the project.

The July recess was the JCP students’ winter holidays and provided a well-deserved break before they started their second-semester modules. However, the international students had to prepare for their final examinations and had to study in the evenings. The logistical and administrative challenges of grouping the students, finding suitable accommodation and providing the necessary documents for visa purposes distracted the lecturer from the academic outcomes. It also increased the lecturer’s workload.

The short-term programme’s benefits could not have been achieved in a conventional lecture setting and participants could compare their social structure with that of Chinese society. This study’s results confirm that it is necessary to provide students with first-hand experiences that reinforce the cultural, social and historical contexts of world cultures.

Including the visiting students in pre-trip preparation, such as project planning, is essential, as it gives them the opportunity to take ownership of the envisaged service-learning project. More guidance and structure must be given to the introduction and pre-visit contact between the students. This will also assist them as individuals and as a group to cope in different environments and to contextualise the students’ safety concerns.

This study shows the value of short international exchange projects, as it provides an authentic setting to develop essential competencies or “soft skills”. This study focused on students’ abilities to transform their civic engagement into civic responsibility as a result of participation in a short-term, international service-learning course. The students’ reflection on their service-learning experiences can be used in other courses, as the short exchange project contributed to students’ broader authentic social responsibility and global citizenship learning. It is, therefore, an investment in the future of local and international students.

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An Analysis of Possible Predictors of Student Early Engagement with Professional Development Opportunities

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Abstract: The University of Sydney has recently introduced a revised approach to industry engagement, where students are required to undertake a diverse range of professional engagement activities continuously throughout their degree program. Experiences with the introduction of this program has shown very diverse levels of engagement by students with the available opportunities - from deep connection to varying degrees of apathy or even antipathy. We hypothesise in this paper that the level of diversity of prior experience and academic study by a student affects their understanding of the nature of practice, and hence will be a strong predictor of their likely level of engagement in the available professional development opportunities. We report on an evaluation of a large data sample (N=350) of first year undergraduate engineering students, exploring correlations between the level of engagement and the diversity of their previous experiences. Our results suggest that the hypothesis is not supported and that diversity of subject choice cannot be used as an indicator of engagement, but that other indicators may have potential if combined in a more complex combination.

Introduction

Despite longstanding debates regarding the role of academic programs in connecting students with the nature of professional practice (see, for example (Shuman, Besterfield-Sacre, & McGourty, 2005)) it is common in most Australian programs to require students to undertake, late in their degree program, a single summer industry internship. Whilst transformative for many students, the University of Sydney formed the view that this was “too little, too late”. From the 2018 semester 1 commencing cohort we have introduced a dramatically revised approach where students are required to undertake a diverse range of professional engagement activities commencing from the very beginning of their degree program (Kadi & Lowe, 2018). Whilst previous research has shown that students generally rate professional internship programs very favourably (Renganathan, Karim, & Li, 2012), our experiences with the introduction of this program has shown very diverse levels of engagement by early stage students with the available opportunities for professional engagement – from deep connection to varying degrees of apathy or even antipathy. If we can understand the predictors of student engagement with available opportunities for professional development then we can potentially develop diagnostic tools and early intervention strategies aimed at increasing the likelihood of student engagement, and hence the potential for strong learning outcomes. We hypothesise in this paper that the level of diversity of prior experience and academic study by a student affects their understanding of the nature of practice, and hence will be a strong predictor of their likely level of engagement in professional development opportunities.
Background

Exposure to professional practice

Historically, engineering and IT programs have recognised the importance of supporting professional development of students (Ryan, Toohey, & Hughes, 1996). Whilst there has been significant debate regarding the extent to which professional skills and a wider contextual understanding can, or should, be taught within the structure of degree programs (Shuman et al., 2005), there is nevertheless broad consensus regarding the importance of this understanding, and the way in which it can strengthen theoretical understanding (Bromme & Tillema, 1995).

The implementation of professional engagement within most Australian Universities has typically been driven primarily by accreditation requirements rather than pedagogic considerations. A key component of the accreditation requirements states:

“The requirement for accreditation is that programs incorporate a mix of the above elements, and others – perhaps offering a variety of opportunities to different students – to a total that can reasonably be seen as equivalent to at least 12 weeks of full time exposure to professional practice in terms of the learning outcomes provided”

(Bradley, 2008)

Based on this, a significant level of exposure to professional practice has been a long-term component of all Australian professional engineering degree programs. The structure of this exposure has however generally been rather one-dimensional and lacked variety – being mostly based on requiring a single twelve-week industry placement, usually in a summer break late in the degree. Whilst for some students this experience has been extremely valuable (indeed transformative (Winberg, Winberg, Jacobs, Garraway, & Engel-Hills, 2016)), for others it had become increasingly problematic: often being ad hoc, poorly supported and/or poorly embedded within the curricula. The problems have often been exacerbated by the challenges of locating high-quality professional experience opportunities for students.

Even where a highly transformative experience is achieved, it is typically late in the degree program. This leads to a question regarding whether there are missed opportunities for using engagement with professional practice by students to enrich their learning earlier in the degree, and whether progressive scaffolding of professional learning across the whole degree could lead to stronger outcomes.

Of course, there are alternatives in existence already, such as 'co-op' programs or other innovative embedded programs (e.g. Drexel’s E4 program (Quinn, 1993)). However, there is still a question of scalability of such alternatives.

University of Sydney: Professional Engagement Program

In responding to the issues identified above, the University of Sydney introduced a new Professional Engagement Program (PEP) for the cohort commencing in semester 1, 2018. The key features of this program include (Kadi & Lowe, 2018):

- Continuous engagement from week 1 of the degree program right through to the end of the degree.
- 3-stage approach with stage 1 focusing on individual performance, stage 2 focusing on team performance, and stage 3 focused on the wider societal context of practice.
- Introduction of 3 zero credit point units of study spanning multiple semesters – PEP 1 [ENGP1000] (3 semesters), PEP 2 [ENGP2000] (3 semesters) and PEP 3 [ENGP3000] (2 semesters). Each stage (unit of study) involves a range of one-off, 2-hour face-to-face workshops beginning with a planning workshop, a review workshop each semester and concluding with an assessment workshop.
• PEP activities, broadly categorised as one of the following 3 types:
  o *Engineering focused* (the red boxes in Figure 1) – in-curricular or extra-curricular – site visits; guest lectures; industry or community projects; industry seminars, workshops or conferences; design competitions or challenges; engineering research projects, etc.
  o *Non-Engineering focused* (the blue boxes in Figure 1) – must be extra-curricular - employment skills; casual employment; volunteering; mentoring; mobility experience; development of transferable skills, etc. Note that the size of the red and blue boxes in figure 1 indicate activities of different durations. One activity might be a 1-hour guest lecture; another activity might be a semester long industry project.
  o *Engineering Work Experience* (the yellow box in Figure 1) – engineering work supervised by a qualified engineer

![Figure 1: Structure of Professional Engagement Program (PEP)](image)

• PEP activity claims – online claims for activities that are lodged in a software system called Sonia. Claims include a description, evidence, Engineers Australia stage 1 competencies developed (selected from a list) and a reflection. These claims are peer reviewed as well as being assessed by academic staff. Students learn about potential activities they can undertake by engaging in peer reviews and also learn about other students’ perspectives on what they learnt and how they learnt it.

All students must achieve an overall total of 600 approved hours of PEP activities over their 4-year degree. In stage 1, the minimum is 80 hours overall but the recommended is 120. At the end of stage 2, the minimum is 220 hours and the recommended is 240. In stage 3, the minimum work requirement is 200 hours, although we recommend students to undertake 420 hours (12 weeks).

The supporting software system has been adapted to allow students to access a dashboard that shows at a glance the total hours gained and remaining in the current stage, broken down by category and overall. An additional dashboard shows the same information but for the entire program. The total number of competencies associated with claims can also be shown and the total hours attributed to each competency development. This allows for periodic competency development auditing and planning for future development activities.

Reflection is a critical component of the program as it is a critical skill that all professionals need to function effectively (Schwartz & Schon, 1987). Techniques and resources to help students develop reflective writing skills reported on previously are being used in this program (Figueroa, Parker, & Kadi, 2014).
Engagement in Activities

Whilst previous research has shown that students generally rate professional internship programs very favourably (Renganathan et al., 2012), our experiences with the introduction of the Professional Engagement Program has shown very diverse levels of engagement by early stage students with the available opportunities for professional engagement – from deep connection with the activities to varying degrees of apathy or even antipathy. This may be related to a lack of understanding of the nature and needs of professional practice by early-stage students (as contrasted with student further into their engineering program – as is typical of more traditional internship programs). This may then in turn be related to their level of experience, and particularly the diversity of this experience.

There has been limited exploration within the literature of the question as to whether a wider breadth of experience can lead to higher levels of performance. For example, Shulruf, Li, McKimm and Smith (2012) considered the connection between breadth of knowledge and grades for students studying health sciences at a large NZ University. Interestingly, they found that breadth of knowledge (as measured by the number of units undertaken at Secondary school) made little difference in terms of achievement in three undergraduate health profession programmes, though the analysis was at a relatively macro level. Lowe, Johnston, Wilkinson and Machet (2018) more recently explored this question in the context of an Engineering program and did find some suggestions that breadth of experience can play a role, but that it may depend on the overall academic capabilities of the students.

Despite this paucity of previous research, preliminary feedback from the Professional Engagement Program did provide some anecdotal suggestions that students with broader experiences might be more engaged with the PEP activities. On this basis we propose the hypothesis in this paper that the level of diversity of prior academic study by a student affects their understanding of the nature of practice, and hence will be a strong predictor of their likely level of engagement in professional development opportunities.

Methodology

In this paper we present an analysis of the level of engagement of a large group of undergraduate students who undertook the first year of the Professional Engagement Program at the University of Sydney in 2018. The overall cohort involved ~800 commencing Engineering undergraduate students. These were a mix of local students straight from high school, students who had transferred from other tertiary programs, and international students. We restricted our analysis to those who were recent NSW school leavers, allowing us to directly compare their high school subject choices and results. This results in a sample size of N=289.

The student sample is split between students enrolled in a single 4-year Engineering degree (N=104) and those enrolled in a combined degree (N=185) that connects their Engineering degree with a second degree (typically Science, Commerce, Architecture or Law). The students are spread across a range of Engineering disciplines including Civil (~30.1%), Aeronautical (~9.0%), Mechanical (~6.9%), Biomedical (~23.5%), Chemical (~7.6%), Mechatronic (~11.8%), Electrical (~4.2%), and Software (~6.6%).

Students’ diversity of experience

For each student in our analysis we have data on:

- The students’ overall high school ATAR (the ATAR – Australian Tertiary Admission Rank – is provided to all Australian graduating high school students and is typically used as the primary basis for University admission in Australia).
- The subjects undertaken in the NSW Higher School Certificate (the secondary school qualifications within NSW) and the results in each subject.
• The engineering course in which the student was enrolled.
• The results in every course attempted within their degree program, and the students’ Weighted Average Mark (WAM).

The consideration of the breadth of previous secondary school studies is complicated as the NSW Secondary School Students have a choice of several hundred different courses. These courses do however fall into a much smaller set of categories, as defined by the NSW Education Standards Authority. Specifically, the courses can be grouped into eight main categories:
  o English.
  o Mathematics.
  o Science.
  o Human Society and Its Environment.
  o Personal Development, Health and Physical Education (PDHPE).
  o Technology.
  o Languages.
  o Life Skills Courses.

We are therefore able to group students HSC courses into these categories and then calculate a measure of dispersion amongst these categories. We have used the dispersion measure defined by Schafer (Schafer, 1980):

\[ D = \frac{k^{N^2 - \sum N_i}}{N^2(k - 1)} \]

Where:
- \( D \) = Dispersion
- \( k \) = the number of categories
- \( N \) = the number of observations
- \( N_i \) = the number of observations in the \( i \)th category

Dispersion is minimal when all the observations are in a single category (and so \( N_i = N \) for that category, and \( N_i = 0 \) for all other categories, giving \( D = 0 \)). Conversely, maximum dispersion is achieved when the observations are spread as evenly as possibly across the categories (i.e. \( N_i = N/k \), giving \( D = 1 \)).

For the purposes of our analysis we considered two variants of the clustering:
- \( D_1 \): Calculated directly using the clusters listed above
- \( D_2 \): Removing the English cluster (as English is the only mandatory course requirement in the NSW Higher School Certificate) and merging Maths and Science into a single cluster (as these related to ‘recommended’ courses for students studying Engineering).

We also calculated:
- \( U_{STEM} \): The number of school units completed in the areas of Mathematics and Science
- \( WAM \): The students weighted average mark in their first semester of study.

**Students’ engagement in Professional Practice Activities**

The first cohort to experience the new Professional Engagement Program was in semester 1, 2018. A total of 52 planning workshops were run during weeks 1-4. The attendance rate was around 95% overall. A total of 54 review workshops were run during weeks 9-12. Attendance was 92.7%. Any student missing either a planning or review workshop received a fail grade.
PEP activity consisted of the workshops as well as lodging claims and the peer assessment of claims. Students were required to submit claims after the planning workshop and before their review workshop. Students undertook peer reviews during their review workshop and were asked to complete one peer review every time they lodged a claim.

In terms of determining an indication of their level of engagement in the Professional Engagement Program we have measures of the student completion of various PEP requirements: prework for planning and review workshops; completion of in-class work during planning and review workshops; attendance at planning and review workshops; and completion of claim forms prior to review workshop 1.

We can then calculate three indicators of the student engagement:

$E_{WKSH}$: Workshop engagement factor: a value representing the proportion of normal planning and review workshop activities successfully completed (with a penalty applied where a student missed a workshop and had to attend a rescheduled workshop); typically, this will be between 0.0 and 1.0, though may be marginally higher if the student has gone on to successfully complete the assessment workshops.

$E_{HRS}$: Hours engagement factor: students should typically have completed a minimum of 55 hours of PEP activities by the end of their first year. This factor is a ratio of hours completed compared to 55 (e.g. 44 hours would give a 0.8 factor).

$E_{PEER}$: Peer review factor: students are required to undertake peer reviews as part of the assessment process whenever they submit a claim. A factor greater than 1 means the student has completed more claims than required, and less than 1 means they have not yet met the requirement.

The overall engagement factor ($E_{SUMM}$) is then the average of the above three factors.

**Results and Analysis**

An initial sense of the nature of the relationship between several of the potential indicators and the student engagement can be seen in Figure 2, which shows the correlations between $D_2$ and $E_{HRS}$ and WAM and $E_{HRS}$ respectively.

To assess these relationships in more detail we calculated the Pearson correlation between each potential indicator and each of the engagement measures – see Table 1. Interestingly, the correlation appears to be strongest with respect to the number of hours claimed by students rather than the other two indicators (workshops and peer reviews). We have therefore included a p value for the correlations with $E_{HRS}$. These shows that whilst the correlations are generally quite weak the correlations between ATAR, WAM and $U_{STEM}$ with $E_{HRS}$ are all statistically significant for $\alpha=0.05$.

To explore the nature of these relationships further we have also considered a range of categorical data (gender, degree type, number of Maths and Science units attempted in the Higher School Certificate) and how these relate to the mean engagement $E_{HRS}$. The results of this are shown in Figure 3.
Figure 2: PEP Engagement ($E_{HRS}$) compared to (a) HSC Subject Dispersion $D_2$ and (b) Weighted Average Mark (WAM).

Table 1: Pearson Correlations

<table>
<thead>
<tr>
<th>Possible indicator</th>
<th>Pearson Correlation ($r$)</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$E_{WKSH}$</td>
<td>$E_{HRS}$</td>
</tr>
<tr>
<td>ATAR</td>
<td>0.023</td>
<td>0.136</td>
</tr>
<tr>
<td>$D_1$</td>
<td>0.031</td>
<td>0.037</td>
</tr>
<tr>
<td>$D_2$</td>
<td>-0.048</td>
<td>-0.057</td>
</tr>
<tr>
<td>WAM</td>
<td>0.239</td>
<td>0.312</td>
</tr>
<tr>
<td>$U_{STEM}$</td>
<td>0.091</td>
<td>0.138</td>
</tr>
</tbody>
</table>
Figure 3: PEP Engagement ($E_{\text{HRS}}$) compared to (a) Gender; (b) Degree type; and (c) number of Science units; and (d) number of Maths units studied in the NSW Higher School Certificate.

As can be seen, in each case there is a significant relationship between the parameter and the level of student engagement.

Conclusions and Recommendations

We had hypothesized that the diversity of subject choices studied in high school would be a strong predictor of a student’s likely level of engagement in professional development opportunities. Our analysis has shown that this is not the case. Whilst there are other potential indicators (most particularly the students’ results at the beginning of their degree program) these indicators have only relatively low correlation with student engagement.

Our objective has been to identify indicators that can be used in predicting likely student engagement, and hence be used as the basis for appropriate intervention strategies early in students’ programs. Our results suggest that subject choices cannot be used to achieve this. Our results do hint that a more complex mix of other factors (such as gender, degree type and specific mathematics and science choices) may have potential. These will be explored in future work. We will also be investigating data from the international students in the cohort.
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Becoming a researcher: A narrative analysis of U.S. students’ experiences in Australia

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Abstract: Undergraduate research experiences are becoming increasingly common in the United States and are encouraged in engineering as a way to give students “real world” problem-solving experience. We sought to understand the experiences of four U.S. students participating in an 8-week summer research program in Australia. Each student participated in interviews before, during, and after the program from which we constructed a narrative for each student describing their critical experiences. Narrative inquiry allows for holistic analysis of a phenomenon without categorizing or sub-setting the data, which can result in loss of context. Using this method, we identified themes across the four narratives to describe the multiple ways in which students assessed their “fit” in the research environment throughout the experience and how participating in the program influenced their future plans. Our findings provide insights for the design and implementation of research experiences both inside and outside of engineering courses.

Introduction
Undergraduate research has been a growing movement in U.S. higher education since the 1980s (Streitwieser, 2009; Taraban, 2008). The foundation of the National Science Foundation's Research Experiences for Students (REU) funding program in 1987 has been followed by support from other foundations, organizations, and universities. The American Association for Colleges and Universities (AAC&U) has recognized undergraduate research as a “high impact practice,” that is, one that has been widely researched and shown to benefit the education of students from a variety of backgrounds (AAC&U, 2007). Within engineering education, undergraduate research has been recognized as an opportunity for students to engage with ill-structured problems in an authentic problem-solving environment (Faber, Vargas, & Benson, 2016). Prior research has identified a range of positive outcomes from undergraduate research experiences, but few studies have focused on understanding students’ experiences during such programs. This study considers the narratives of four U.S. students conducting research during a summer in Australia to explore the ways in which the students interacted with the “research environment.” Understanding the process of how novices engage with research can inform the design of undergraduate research programs and course-related research activities.

Relevant Literature
Although engineering programs often emphasize problem solving as a core skill for engineers to develop, they have been critiqued for primarily providing students with well-structured, closed-ended problems to solve (Jonassen, 2014). Recent developments in educational practice have been working to address this concern and improve the in-class experiences of engineering students (Kolmos & de Graaff, 2014). However, engineering students can also develop skills and expertise through extracurricular activities that foster problem solving (Murzi, 2018; Strauss & Terenzini, 2007). Undergraduate research experiences have been recognized as one method to expose engineering students to an
authentic problem solving environment that complements the content learned in coursework (Faber et al., 2016; Murzi, 2018). Such experiences can also provide students with the opportunity to participate in a professional community of practice in a legitimate way (Hunter, Laursen, & Seymour, 2006; Thiry, Laursen, & Hunter, 2011). Learning in such an environment involves socialization of “newcomers” into the practice of the community (Lave & Wenger, 1991), which can support the development of identity or affinity with the profession (Hunter et al., 2006).

Investigations of undergraduate research experiences have highlighted a variety of positive outcomes (Taraban, 2008). At the most basic level, such experiences expand students’ research skills and confidence in their ability to conduct research (Kardash, 2000; Seymour, Hunter, Laursen, & DeAntoni, 2004). These skills include data collection, data analysis, theoretical understanding, and awareness of how to approach research problems. Further, students report gains in the attitudes necessary to participate in a research community, including taking responsibility for a project, decision-making in a research context, and intellectually engaging in research discussions (Hunter et al., 2006; Seymour et al., 2004; Thiry et al., 2011). These outcomes have been described as the process of “becoming a scientist,” indicating students’ experiences of moving from peripheral to more full participation in the research community (Hunter et al., 2006). Such benefits are stronger for students who participate in research projects for an extended period of time (i.e., multiple semesters; Thiry, Weston, Laursen, & Hunter, 2012). Development of research skills and attitudes has been reported not only by student researchers themselves, but also by their academic mentors (Hunter et al., 2006; Kardashian, 2000). However, not all undergraduate research experiences are identical. Variations in program components, such as time spent with academic mentors or in the laboratory, have been shown to correlate with both the skill- and attitude-based learning outcomes of undergraduate research (Taraban, Prensky, & Bowen, 2008).

Within the engineering education community, similar findings have been reported about students’ development of a researcher identity (Benson et al., 2018; Faber & Benson, 2015). Students reported that they felt recognized as researchers through working on independent projects, presenting their work, receiving acknowledgement from research mentors, and talking about their research to people outside their field (Faber & Benson, 2015). Faber et al. (2016) also identified profiles of emergent researchers as they move from being a novice researcher toward contributing actively within a community of practice. This process was found to be related to both longer research experiences and increasing levels of autonomy within the research project. A novice researcher tends to be very dependent on research mentors with little decision-making responsibility, whereas a contributing researcher has become involved in making research decisions and feels integrated within the lab (Faber et al., 2016). Faber et al.’s (2016) work provides a closer look at the process through which students move from being a novice to a contributing participant in a research community. However, the existing research both inside and outside engineering education has been primarily dependent on pre/post assessment or simply post-experience interviews/surveys. Our study sought to explore undergraduate research throughout the entire experience to shed light on critical moments in students’ engagement with the research community.

**Theoretical Framework**

Because the focus of this study was on understanding student narratives without prior expectations or hypotheses, we did not use a theoretical framework in the design of the study. However, after completing the narrative development process, we noticed several common themes across students’ experiences that connected to ideas present in the *Person-Environment Fit* theoretical framework. Person-environment (PE) fit has been defined as “the congruence, match, similarity, or correspondence between the person and the environment” (J. R. Edwards & Shipp, 2007). Although a variety of PE fit theoretical models have been proposed over the years (J. R. Edwards, 2008), there are several common components across theories (J. R. Edwards & Shipp, 2007). A meta-analysis of PE fit
research suggested that PE fit is a multi-dimensional construct based on the fact that each dimension shows different influences on individuals’ attitudes, organizational commitment, job satisfaction, and job retention (Kristof-Brown, Zimmerman, & Johnson, 2005).

J. R. Edwards and Shipp (2007) present a conceptualization of PE fit that organizes these concepts into three dimensions: Type of Fit, Level of the Environment, and Content Dimensions. The Type of Fit dimension describes differences between supplementary fit (i.e., similarities between person and environment) and complementary fit (i.e., weaknesses in person or environment are offset in strengths of the other). Complementary fit can be further divided into demands-abilities fit (i.e., environmental demand met by a person’s abilities) and needs-supplies fit (i.e., person’s needs met by an environment’s supply). The Level of the Environment dimension captures the idea that fit can be identified between a person and different levels of their environment, including: individuals, a job, a group, an organization, and a vocation. Lastly, the Content Dimensions describe the characteristics by which PE fit are being analysed, ranging from general to specific. Three points on this continuum are identified: global (i.e., comparison in a general sense), domain (i.e., comparison on a broad variable), and facet (i.e., comparison on specific dimensions of a variable). Subsequent work has suggested that these conceptual dimensions may combine to form an overarching sense of PE fit (Jansen & Kristof-Brown, 2006), but initial findings have not supported this idea (J. A. Edwards & Billsberry, 2010).

Methods

In our study of undergraduate research participants, we used narrative inquiry as a way of understanding participants’ experiences holistically. Narrative inquiry allows stories to be analysed in their entirety rather than coded and categorized as is typical in other forms of qualitative research (Kellam, Gerow, & Walther, 2015). Keeping stories intact allows researchers to understand the larger experience under study and identify themes that run throughout. Although relatively new in engineering education research, this method has been used in prior studies of engineering major choice (Cruz & Kellam, 2018), career decisions of engineering teaching faculty (Trellinger & Jesiek, 2017), and boundary spanning experiences of early career engineers (Jesiek, Trellinger, & Nittala, 2017). In this study, we used interviews from across a summer research experience to construct student narratives about their engagement with the research environment.

Participants

The participants for this study were four U.S. civil engineering students participating in an eight-week summer research program in Australia. The program was funded through the National Science Foundation’s International Research Experience for Students (IRES) program, which supports research collaborations between U.S. universities and partner universities abroad. Students were admitted to the IRES program through an application process that included submission of a transcript, a CV, and a short essay of research interest. Students were selected based on their prior research and academic experience and interest in the research available at the partner university, with the intent of identifying students who would be successful in the program. During the program, students were paired with an academic at the partner university and assigned to work on one of their research projects. All of the students participated in various parts of the research process, with an emphasis on gaining fieldwork experience. The students had opportunities for both short-term (i.e., one-day) fieldwork trips and a longer-term (i.e., 1+ weeks) experience.

All students were required to participate in data collection as part of the evaluation process for the grant, but we obtained their consent to use the data for research purposes in line with the requirements for human subject research provided by the Institutional Review Board. Details about the participants are shown in Table 1 below.
Table 1. Overview of Participants

<table>
<thead>
<tr>
<th>Participant #</th>
<th>Prior Research Experience</th>
<th>Prior Global Experience</th>
<th>Gender</th>
<th>Year in School</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Only class projects</td>
<td>2-week study abroad in high school</td>
<td>Male</td>
<td>Senior</td>
</tr>
<tr>
<td>2</td>
<td>One semester</td>
<td>2-week study abroad in college</td>
<td>Female</td>
<td>Junior</td>
</tr>
<tr>
<td>3</td>
<td>One-week field trip</td>
<td>2-week study abroad in college, family travel</td>
<td>Female</td>
<td>Junior</td>
</tr>
<tr>
<td>4</td>
<td>Eight-week summer research, two semesters</td>
<td>Eight-week summer research abroad</td>
<td>Male</td>
<td>Senior</td>
</tr>
</tbody>
</table>

Data Collection

Each student participated in four semi-structured 30-minute interviews throughout the program. The timeline and content of this interview sequence are shown in Table 2. All of the interviews were conducted by the graduate student evaluator for the IRES grant, who travelled with the students to Australia for the summer. The middle two interviews were scheduled to occur before and after the longer fieldwork experience for the summer.

Table 2. Interview Sequence

<table>
<thead>
<tr>
<th>Interview #</th>
<th>Timing</th>
<th>Content</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1-month pre-program</td>
<td>Prior research and global experiences, expectations, concerns, understanding of research process, career goals</td>
</tr>
<tr>
<td>2</td>
<td>Mid-program pre-fieldwork</td>
<td>Research experience to this point, prior fieldwork experiences, expectations for fieldwork</td>
</tr>
<tr>
<td>3</td>
<td>Mid-program post-fieldwork</td>
<td>Research experience to this point, fieldwork experiences, lessons learned, research process, career goals</td>
</tr>
<tr>
<td>4</td>
<td>1-month post-program</td>
<td>Overall research experience, transition back to school, lessons learned, key experiences, career goals</td>
</tr>
</tbody>
</table>

Data Analysis

All of the interviews were transcribed and then developed into narratives using the narrative construction method (Kellam et al., 2015). This method involves using direct quotes from a student’s interviews to construct a narrative story about their experience with connecting text added by the researcher to improve the flow. To help the narrative read more naturally as a story, the story is written in first-person and quotes are not indicated in the text. The narrative construction method has the benefit of removing authorial distance (by writing in the first person) but can reduce narrator reliability by not indicating direct quotes. This method was selected because of its ability to develop a holistic account out of a series of events, bringing order and meaning to the data (Kellam et al., 2015).

The researcher developing the narratives first read through each of the interview transcripts in depth. Then, focusing on one participant at a time, she reviewed each interview again and identified quotes describing key events, experiences, and student responses (i.e., critical incidents). These quotes were moved to a spreadsheet and grouped based on the critical incident or experience they described. The narrative for each student was then constructed around the critical incidents, moving both chronologically and from general experiences to more specific incidents. The final narratives were reviewed holistically by both researchers, who then identified connections to PE fit framework (the framework was not part of the study during narrative construction and was only introduced during the final cross-narrative
analysis and interpretation). The overarching narrative presented in this paper describes the common themes across all four narratives in light of PE fit concepts.

Limitations

This study is limited by its focus on students who participated in a single program (which was a convenience sample). Research experiences take a variety of forms, so this study of summer research experiences may not be transferable to all research experiences. Summer programs may be more likely to give students their own projects to work on as they are dedicated to doing research full time compared to within-semester research experiences. A second limitation is that all the student participants came from the same department at the same institution. Institutional variables are relevant in the experiences of undergraduate students, so it will be important to consider context in interpreting the results for potential transfer to other situations. This IRES program sent students from a large research-based institution in the mid-Atlantic region of the U.S. to a large research-based institution in Australia. Research programs in other contexts may result in narratives different from those described in our study.

Findings & Discussion

In this section, the four narratives are discussed as a group to explore the similarities and variations across the four students’ experiences in the undergraduate research summer program. The key finding from this study is that all four students described different ways that they were exploring the research environment for potential fit with their future career plans. Thus, we have introduced terms from the PE fit theoretical framework to structure the discussion and highlight the various ways that a student may determine that they do or do not “fit” into the research environment. The three levels of fit that were most central to the student narratives were: person-individual fit, person-group fit, and person-vocation fit. Within each of these categories, the other dimensions of the PE fit framework also emerged as relevant factors in students’ overall experiences (highlighted in italics in the following sections). Direct quotes are not included in reporting the findings to avoid isolating pieces of the narratives. This decision was made based on prior examples of narrative research (e.g., Cruz & Kellam, 2018; Trellinger & Jesiek, 2017). Rather, the narratives have been considered holistically and overarching storylines are reported and discussed in the context of prior research. A longer excerpt from one of the narratives is included in Appendix A to provide an example of the final narrative format.

Person-Individual Fit

Connecting with a mentor during the research program was a critical experience for most of the students. Although prior work has highlighted that time spent with academic mentors can improve student learning outcomes (Taraban et al., 2008), the students found that their more meaningful connections often occurred with graduate students. This observation was particularly important for students working for academics who took a hands-off supervisory approach. One student emphasized that without their graduate student mentor, the summer would have been a miserable experience with little guidance. Another felt that discussing their project with their mentor was the best way to learn more about the field. The students all provided examples of how their mentoring relationships contributed to their overall success, creating a needs-supplies fit within their summer research experiences.

Across the narratives, students pointed to a variety of positive outcomes from the development of a mentoring relationship. Similar to the earlier research on the development of research skills (Kardash, 2000; Seymour et al., 2004), most students discussed learning about the research process and how to conduct fieldwork experiments. Several students emphasized that working closely alongside their mentor allowed them to observe different skills first and then put these into practice in their own projects. However, the mentoring experience often went beyond the basics of helping students develop the skills necessary to complete their projects. One student observed their mentor’s approach to work-life balance
and willingness to take time to help others despite being busy with projects. Another had opportunities to discuss current events with their mentor while doing fieldwork and became more comfortable interacting with professors in general. A third discussed how their mentoring experience helped them understand the importance of finding a supportive advisor in graduate school. Thus, although most students found person-individual fit within a mentoring relationship, the domain (i.e., content) of this connection varied across students.

Although person-supervisor fit is a common relationship considered within the PE fit literature (J. R. Edwards & Shipp, 2007), the students in this study tended to emphasize the importance of feeling like a colleague in their mentoring relationships. Over the course of the summer, several of the students discussed developing confidence in themselves as a researcher because their mentor treated them as one. As mentors assigned the students more complex tasks, the students could see that they were being trusted with important parts of the project. One student described how their mentor eventually stopped getting out of the car during a fieldwork trip and let them collect all of the samples. Another student whose supervisor entrusted them with the management their own project began to see themselves as a leader and consider how this experience might relate to a career as a professor. The students’ progression towards seeing themselves as colleagues to their mentors shows movement from peripheral to more complete participation in a research community of practice, aligning with the findings from earlier work (Hunter et al., 2006; Lave & Wenger, 1991). However, the narratives also suggest that demands-abilities fit is important in making this transition. The students began with different levels of research skills, and it was important that their mentors assigned tasks that aligned with their initial skill level and continued to adjust for their growing confidence and understanding over the course of the summer research experience.

**Person-Group Fit**

Throughout the summer, each of the students described assessing their fit with different groups within the research environment. Where the students’ person-individual fit assessments tended to focus on complementary fit (i.e., person and environment meeting each other’s needs), their person-group fit assessments focused on supplementary fit (i.e., similarities between person and environment; J. R. Edwards & Shipp, 2007). For example, research groups are one of the most common groups encountered in the research environment. The summer research program gave students access to two research groups focused on related research topics. Students assessed their fit with these groups based on a variety of domain (i.e., content) characteristics. Some students focused on the research topics of the groups and identified which research group aligned better with their personal interests. Others focused on the communication and interpersonal practices of the groups and found certain team environments more or less aligned with their preferences.

Because the research program took place in Australia, another assessment that several students made was their fit within Australian culture. Most students described the differences in work-life balance attitudes and “whole being health” as positive aspects of the culture that they admired and wanted to emulate as much as they could upon returning to the U.S. These students identified supplementary fit between these Australian cultural values and their personal values and aspirations. On the other hand, some students identified a lack of fit between the casual, unstructured nature of the Australian work environment and their preferences. One student also discussed how the Australian sense of humour was significantly misaligned with their own and that it had surprised them how important this misalignment turned out to be. This student concluded that they would prefer not to live in a place where they could not tell whether people were joking.

The students’ various assessments of person-group fit played a significant role in their resulting thoughts about future graduate school experiences. Most students completed the research experience with a more refined sense of their research interests and discussed how this would guide their choice of graduate programs, advisors, and research projects. Some
students expanded on this topic by emphasizing the importance of studying a topic they are passionate about (an example of person-job fit). Other students commented on how their experiences in the different research groups helped them understand the importance of fitting in with the people they would work with. These students planned to carefully research the group culture of graduate programs to which they applied. Lastly, one student interested in going abroad for graduate school emphasized the importance of researching the cultures of the countries they considered to ensure some alignment between their personal values and preferences and those of the host culture. Although previous work has identified interest in graduate school as an outcome of undergraduate research programs (Hunter et al., 2006; Seymour et al., 2004), we found that students also had more nuanced perspectives on what they wanted and needed in their graduate school experiences.

**Person-Vocation Fit**

Because undergraduate research experiences often function in an apprenticeship model, they present an opportunity for students to “try out” research as a possible future career (Hunter et al., 2006; Kardash, 2000). It was evident across all of the student narratives that assessing person-vocation fit was a central part of the summer research experience. Several of the learning outcomes of undergraduate research experiences that have been discussed in earlier studies turned out to be important as students made this assessment, specifically: 1) learning to ask research questions, 2) understanding the research process, and 3) developing fieldwork data collection skills. As students came to understand these aspects of research as a vocation, they either found themselves confirmed or confused about their plans to pursue a research career. Because the students were assessing specific components of the research career for alignment with their preferences, they were assessing supplementary fit at the facet content level.

All of the students discussed the ill-structured nature of research projects and how this was a contrast to their prior work in engineering coursework. Most of them connected this contrast to the types of questions that research works to address, describing them as “broad,” “open-ended,” and “vague.” Similarly, students discussed the “non-linear” and “flexible” aspects of the research process, emphasizing that there was no single correct approach. Throughout the summer, the students engaged in the process of learning to ask research questions and identify a strategy to try to answer them. For some students, this experience was freeing, allowing them to use creativity and develop skills in self-directed learning. For others, the ill-structured nature of the questions and projects was more overwhelming. One student described feeling “intimidated” when faced with a research question and not sure where to start. Working with a mentor to develop a plan with some structure helped this student, but the overall experience caused them to question their vocational fit with research. Fieldwork experiences also highlighted the inherent uncertainty in research as a vocation for several students. Although all of the students enjoyed their fieldwork and cited it as a highlight of the summer, some of them truly relished the “troubleshooting” nature of the work. Overall, the ill-structured nature of research projects seems to be a facet of the research vocation that attracted some students and repelled or at least challenged others.

Another facet of the research process discussed by some students was the level of interaction with other people. Some students found that research involved more collaboration than anticipated and appreciated being part of a team. On the other hand, some students noted that research involved a lot of individual work and wondered if another vocation would provide more opportunities for interacting with people. Thus, although they were all working on projects in the same research groups, the assessment of whether research involved “a lot” or “little” personal interaction varied across students.

At the start of the summer, each of the students expressed an expectation that they would pursue graduate school and likely a research-related career. Students who were more comfortable with the ill-structured nature of the research process further confirmed their plans. These students compared their summer research favourably against prior industry
internship experiences, where their projects had been more structured and supervisors more hands-on. In comparison, students who were intimidated by the open-ended questions or uncertainty of research projects questioned their initial plans. One student decided by the end of the summer that they would prefer a job in industry, feeling that this would allow them to “take action” based on research findings rather than work on the open-ended questions. Similarly, a student who wanted more interaction with people began to consider law school as an option for finding better person-vocation fit. In each of these cases, learning about the research process helped the students assess their fit with research as a vocation.

Implications & Future Research

Although prior research has identified positive outcomes of undergraduate research, our findings provide a more nuanced perspective. Through the lens of the person-environment fit framework, we identified various ways that the students in our study used critical experiences in their research program to assess their fit within the research environment. Our findings support earlier research suggesting that specific program components may influence student learning outcomes (Taraban et al., 2008) and provide insight into the different ways that students respond to these components. For example, being mentored by academics, participation in research groups, and exploring ill-structured problems can all lead to different interpretations from different students. We suggest that these differences may be because students are using these experiences to assess person-environment fit.

Based on these findings, we suggest that undergraduate (and potentially also graduate) research experiences could be facilitated with the intent of helping students make these assessments. If a desired outcome of such programs is to encourage students to consider graduate school and/or a career in research, it is important to include authentic research experiences to enable accurate fit assessments. It is also essential that program facilitators acknowledge the different prior experiences, values, and expectations of different students. This means that providing the same experience to several students may lead to varying results. Checking in with each student periodically throughout a research experience may help identify questions or concerns that individual students are facing as they seek to assess their fit in the research environment—and it may help them process those feelings. Although our study focused on a summer research program, we believe that these recommendations could apply in either a course-based or extracurricular research experience.

Our study was limited in its focus on a single program and small number of students. Future work could explore student experiences across different types of research programs to see how they vary. Based on our experience, we would recommend the use of narrative inquiry as a way to see a holistic story within data. The process of constructing the narratives, although time consuming, was valuable in providing a structure through which to analyse data collected over several interviews. By capturing data at several points in time, we gained a unique perspective on student development as a process, which can be overlooked in the pre/post analysis often used in educational research. Reading the narratives also allowed us to see connections between student experiences and their subsequent conclusions and decisions about the research environment, providing insights that may have been lost using traditional qualitative methods.

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**Appendix A**

The following is an excerpt from the narrative for Participant 2. This section represents one critical incident from their summer experience: being mentored by a Ph.D. student.

*One of the highlights of my summer was working closely with the PhD student on my project. I remember the moment where he came up to my desk and asked “Hey would you want to work on this for me?” It was so satisfying to have that acknowledgement, because I didn’t ever talk to the faculty advisor I had been assigned, which was very upsetting. But this PhD student took me under his wing, explained everything to me, and really went out of his way to make me feel like I was working towards something. I would have had a miserable time if he had not stepped up to that role.*

*As a part of the mentoring experience, the PhD student I worked with would give me papers to read and ensure that I understood them. He gave me smaller tasks to work on and I would always tell him to give me literally anything to do, because sometimes even dumb tasks teach you a lot. Just working next to him and seeing what he did every day was helpful. I felt like I was able to do tasks that he already knew how to do so he could work on more difficult things. At the same time, he did a really good job of showing me the whole process and making sure I understood how my tasks fit into the bigger picture.*

*Ultimately I realized that which project I worked on didn’t matter as much as having a supportive mentor. Getting that one-on-one interaction where he could answer my questions was way more important than being on a specific project. I felt like I learned a lot even if I didn’t come up with as many deliverables as I might have wanted. I know some of the other students managed their own projects, but I would definitely have chosen to help someone out, because I have realized that you can learn a lot from working with someone else.*

*This experience has really shown me what I want in a graduate school program. I definitely want good mentorship and to feel like I am supported. That’s my bare minimum requirement, because I don’t know if I would do well with an advisor that isn’t supporting me at all.*

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Using continuous feedback as an alternative form of students’ evaluation of teaching

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Abstract: In this study, I evaluated the impact that providing feedback in a first-year engineering course had in students’ perceptions of teaching. An experiment was conducted with a section of 28 students in the control group and a section of 34 students in the experimental group. In the experimental group, students had the opportunity to provide weekly feedback about the course. Changes to the course on both sections were made based on the feedback. Results suggest that students in the experimental group had a better performance in the course and also had a better perception of the course at the end of the semester.

Introduction – overall layout

Effective pedagogical practices have been studied in the engineering education field for decades. Despite teaching being one of the most important roles for faculty members, methods to assess effective teaching practices are limited in the literature (Dee, 2007). Currently, evaluation of students’ perceptions of teaching, at the end of the semester, is almost the only metrics being used to assess a faculty member teaching effectiveness, yet, student evaluations of teaching are commonly used in faculty performance reviews. Although students’ evaluation of teaching have proven to be valid and reliable (Cohen, 1981; Marsh, 1987), several instructors consider them not an ideal metric to evaluate teaching performance since they (i) are conducted at one point only, usually at the end of the semester; (ii) not every student fills out the evaluation; (iii) students that tend to fill out the evaluation have strong (positive or negative) feelings about the instructor; and (iv) in some cases, evaluation scores can correlate to students’ grades rather than to effective teaching (i.e. students receiving good grades provide good evaluations even if the teaching was poor). In addition, it is important to consider the generational context of the students that are currently in college. Research in human resources suggest that new generations are more comfortable in working environments where they are able to provide and receive feedback continuously (Hall, 2016; Stewart, Oliver, Cravens, & Oishi, 2017; Willyerd, 2015). Feedback seems to be something that the new generations value, teaching feedback is also something that instructors value, therefore, learning environments should be able to provide those spaces for continuous feedback and faculty members should use continuous feedback as an alternative way to evaluate their teaching. Continuous feedback provides an opportunity to actually make changes to teaching practices during the semester, so students providing feedback can benefit directly from the process.

The purpose of this paper is to evaluate the impact that allowing students to provide continuous feedback had on a first-year engineering course. More specifically, my research question is: what is the impact that having a continuous feedback channel has on students’ performance and perceptions of teaching?

Literature review

Several approaches have been taken in engineering education to find different alternatives to improve teaching. Finelli et al. (2008) analyzed instructional consultants as a way to provide support to engineering faculty. The authors suggested that instructional consultations should be available and offered systematically and proactively. This approach can help faculty members improve their teaching, however, it does not provide an alternative option to
evaluate teaching effectiveness. Johnson, Narayanan, and Sawaya (2013) investigated how course and instructor characteristics affected students evaluation of teaching, concluding that faculty demographics, and average course grades had significant effects on the evaluation. For a similar reason, Stark and Freishtat (2014) oppose students evaluations of teaching since the authors consider that it does not measure effectiveness of teaching. The authors encourage faculty members to find alternatives way to evaluate teaching effectiveness.

Although Stark & Freishtat (2014) might be against students evaluation of teaching, the authors do recognize that such evaluations provide valuable information about students' experiences in the course. It seems like students’ motivation to fill out those surveys is focused on their opportunity to have a voice and contribute to improve the course (Giesey, Chen, & Hoshower, 2004). I argue that providing students with the opportunity to have a voice in the course could be positively related to students’ performance and a positive students’ perception of the course and can provide faculty members with an alternative way to evaluate their teaching effectiveness.

**Methods**

In order to answer my research question I developed a post-test only control-group experimental design (Creswell & Creswell, 2017). In this study, students were randomly assigned to two sections (experimental and control). The same instructor was teaching both sections. The experimental group received the opportunity of providing feedback weekly, and everything else in the course, for both sections, was maintained the same. At the end of the semester, several measures were considered to identify if providing feedback had an impact on the students.

**Participants**

Participants in this study were first-year engineering students enrolled in a foundations of engineering course in a research intensive university. The control section class schedule was every Monday and Wednesday from 8:00am to 9:15am, the experimental section had class every Monday and Wednesday from 9:45am to 11:00am. There were 28 students in the control group and 34 students in the experimental group. In the control group 82% of the students were male and 18% were female, and 10% were international students. In the experimental group there was the same gender proportion and 9% were international students. These demographics are representative of the first-year engineering student population at that institution.

**Treatment**

The context in which this study was conducted was on a first-semester foundational engineering course. Students enrolled in engineering at the University go through a first-year general engineering course before declaring their engineering major at the end of the year. The Foundations of Engineering course is the first engineering course in a sequence to introduce general engineering students to the profession. The course has the following learning outcomes: to (1) Compare and contrast the contributions of different types of engineers in the development of a product, process, or system; (2) Articulate holistic and ethical issues that impact engineering solutions; (3) Solve problems using systematic engineering approaches and tools; (4) Model an engineering system; (5) Communicate solutions and arguments clearly; and (6) Develop teamwork skills.

The class is structured in 3 different modules where students work individually and in teams in different projects to develop the learning outcomes. Module 1 is about engineering opportunities. Individually they have to explore their interests in engineering and create a plan to select a major. In teams they need to work on a project to understand how a product works, and reflect on how different engineering disciplines interact to create it. Module 2 is about data and modeling, students use an engineering tool (i.e. MATLAB) to represent and analyse data and to model an engineering system. Module 3 is about unpacking engineering
problems. Individually students in this module need to formulate an ill-structured problem, in teams they work in a project to systematically un-pack a complex ill-structured problem.

**Procedures**

In this study I analysed two sections of the foundations of engineering course. In the experimental group, every Wednesday students had the opportunity to provide feedback by filling out an anonymous online survey. At the end of the session students were given 3-5 minutes to individually respond to three questions (1) What did you find helpful in today's class? (2) What did you find difficult or not helpful in today's class? (3) What should we change? Students were provided with a Qualtrics link where the survey was designed and data were managed.

Each week I would summarize the responses and discuss them with the graduate teaching assistant (GTA) of the class and we created a plan for the following week that took into consideration the feedback we were receiving. The course became dynamic in the sense that we were adapting and changing things around based on the feedback. Changes were included both in the control and experimental group, however, the control group was never informed about the changes nor where they were coming from. The experimental group, on the other hand, every Monday started the week with a slide that summarized the feedback from the previous week and explained the changes done to the course based on the feedback. I also discussed the reasons behind some of the feedback that was not possible to take into consideration. For example, sometimes students requested for a deadline extension in an assignment, however I explained that I couldn’t change the deadlines because some projects were common projects the department assigned to every section in the course (around 50 sections overall). Overall, during the semester, I received on average 300 responses to every question, in the following paragraphs I summarize the feedback received and provide examples on how the course changed accordingly.

Regarding the first question and what they were finding helpful in class, students expressed the importance of doing hands-on activities and in-class challenges -as opposed to lectures- and the value of discussing and reflecting on the activities during the same class time. Students also found detailed explanations of assignments and expectations useful. It seems like at their level they are not expecting to figure things out on their own. Regarding topics that they consider helpful to learn, students commented that discussing the differences between engineering fields was very helpful because by the end of freshman year they will have to declare their major. In addition, they consider learning about MATLAB, data, communication, decision matrices, and presentations useful. Regarding resources, students found helpful the online websites provided for support, how to use the library database, or showing them where to find information on a project. Students also found that the emphasis on teamwork in this class allowed them to build skills that helped them succeed in class and that being able to work in a team and collectively solve problems was beneficial to understanding the material. Finally, students benefited by watching the instructor work through the logic of a problem and do it along with them. This allowed the students to not only see the proper steps and thought process but to also do it themselves making them reach an understanding to be able to do it on their own later.

In terms of what students found difficult in the class, there were several topics that students found challenging and where I made several course adjustments accordingly. At the beginning of the course, students commented on course instructions and finding it difficult to understand some of the assignments and the expectations. To change that, I developed additional documents for each module where I explained in detail all the assignments for the module and provided a rationale behind each assignment. I also connected the learning outcomes of the course to the deliverables of the assignments in the module so students could understand where things were coming from. In addition, I provided students with the rubrics that were used to grade all their assignments. Students also commented about confusion on some grades, I consider this to the fact that one GTA and two undergraduate
Graders were supporting me with grading. To minimize frustration with grades I established a procedure so students could talk to me directly when they were not happy with a grade, several students during the semester used it and I reviewed and regraded their assignments. Although the grade usually didn’t change, I was able to provide more detailed feedback. Another difficult aspect for the students was the coding part of the course. For some students, coding in MATLAB was completely new. To overcome this challenge the GTA offered extra hours to work with students. I also included a CANVAS (online course management system) page with MATLAB basic tutorials. Another challenging topic for them was how to find valid resources online and bring those sources as evidence in their reports. We created a session on how to find valid information that was co-developed with someone from the University Library, in addition we created two documents with guidelines on (a) how to find valid information, and (b) how to use IEEE citations. Students also commented on having challenges with their teams so I emphasized more on the importance of using a team contract (I provided the template). Finally several students commented on challenges on specific assignments or lessons, since these were very specific, the changes made to the course based on this feedback was to go over the main points of the assignment or the lesson the following week and make sure students had plenty of time to ask questions and for clarification.

Regarding the last questions and the things students would like to change, students commented on three different aspects: methods of instruction, deadlines and grading, and issues regarding the classroom. In terms of methods of instruction, students provided feedback when a topic was fast-paced, so I included more time the following week to make sure they understood it, I also became more aware of my own pace when teaching. Several students were also having issues with learning MATLAB and coding, so I started solving problems in real time with them, students thought that was really useful and several of them in the following week pointed this out as one of the things were helpful. Students also commented on their desire to have more time to work during class with their teams. One of the changes I made was to have them do two of their team projects during class time. Not only that allowed the students to easily find a common time to work on the team project but also allowed me to supervise how the teams were working together and identify potential team conflicts. In terms of grading and deadlines, as discussed before, many deadlines I was not able to change so I had open conversations with the students regarding why I couldn’t change them and the reason behind having those specific deadlines, also in terms of grading I established additional procedures as explained above. In terms of comments on the classroom some students commented on their desire to have more tools in the classroom when doing hands-on assignments, I commented on this issue and told him we were trying to get more tools, some students also commented on issues like the temperature of the room, so I made sure to ask them every week if they were too cold/hot.

Measures

According to Creswell and Creswell (2017) it is important to obtain measures during the experiment that allow researchers compare the experimental and the control group. In order to identify the impact that providing feedback had on students’ perceptions of the course, data were analysed quantitatively using two different data sources. One data source were students’ grades. Since both sections had the same structure and the same assignments, I compared the grades that students obtained in each assignment. In addition, the other data source used in this study were end-of-semester students’ perceptions of teaching (SPOT) surveys. This survey is anonymous and is taken by the students at the end of the semester. Data were analysed using the SPSS statistical software. Descriptive statistics are presented and T-tests were conducted in both data sources to identify significant differences in the results. The study security ethical clearance by the institutional review board (IRB).
Limitations

The present study has several limitations. First, there are some threats to validity that should be considered and might influence our results. For example, students enrolled in the control group attended class on Mondays at 8:00am, historically this has been the least preferred schedule for college students, therefore students' motivation in the course could be affected. In addition, the only two data sources to evaluate the impact of the course are grades and SPOT surveys. Grades are a valid way to evaluate performance in a course, however, is not directly related to the intervention. SPOT surveys are also a subjective evaluation of the general course that does not have much acceptance in the engineering education community (see literature review section earlier in this paper). Hence, I would suggest take this limitations into consideration and be cautious when making generalization of the findings in this paper.

Results

Grades

Students' grades in the control and experimental group varied significantly. In terms of the overall final grade, the control group had an average of 83.09% as the experimental group had an average of 89.78%. In Figure 1, overall final letter grades are presented for both groups. In the control group, grades are distributed consistently among different grades, however, 10.71% failed the course as opposed to 2.94% in the experimental group. In addition, the experimental group has better final grades overall since 55.88% of the students obtained an A, the highest possible grade in the course.

![Final Grades](image_url)

Figure 1: Final letter grade by group

The course grades were divided in four different sections. Module 1 represented 25% of the grade, module 2 35%, module 3 30% and there was a 10% for all the other miscellaneous assignments in the course (i.e. homework and class participation). The differences in each grade section between the control and experimental group are presented in figure 2. In addition, an independent sample T-test was conducted to identify if there were significant differences in the grades in each section. Results of the T-test are reported in table 2. The assumption of homogeneity of variances was tested and satisfied via Levene’s test and the level of confidence assumed was 95% (p=0.05). In module 1, I found statistically significant differences between the grades for the control group M = 84.14 (SD =11.61) and the experimental group M = 90.77 (SD = 7.09). Similarly, in Module 3, there were significant differences between grades of the control group M = 81.39 (SD = 10.88) and the experimental group M = 90.14 (SD = 6.82). The overall final grade difference between the sections also presented statistically significant differences with the control group M = 83.09
(SD = 12.14) and the experimental group M = 89.78 (SD = 8.11). It is important to note that in the two modules were there was not statistically significant differences (i.e. module 2 and miscellaneous assignments), the majority of the assignments were individual.

![Grades comparison](image)

Figure 2: Grades comparison for each section of the course

<table>
<thead>
<tr>
<th></th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
<th>Mean Difference</th>
<th>Std. Error Difference</th>
<th>95% confidence interval Lower</th>
<th>95% confidence interval Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module1</td>
<td>-2.642</td>
<td>42.84</td>
<td>0.011*</td>
<td>-6.63174</td>
<td>2.50987</td>
<td>-11.69393</td>
<td>-1.56956</td>
</tr>
<tr>
<td>Module2</td>
<td>-1.441</td>
<td>60</td>
<td>0.155</td>
<td>-5.69494</td>
<td>3.95077</td>
<td>-13.59765</td>
<td>2.20778</td>
</tr>
<tr>
<td>Module3</td>
<td>-3.857</td>
<td>60</td>
<td>0.001*</td>
<td>-8.74769</td>
<td>2.26803</td>
<td>-13.28443</td>
<td>-4.21095</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>-1.754</td>
<td>60</td>
<td>0.085</td>
<td>-3.89758</td>
<td>2.22219</td>
<td>-8.34262</td>
<td>0.54745</td>
</tr>
<tr>
<td>Final grade</td>
<td>-2.589</td>
<td>60</td>
<td>0.012*</td>
<td>-6.69023</td>
<td>2.58438</td>
<td>-11.85975</td>
<td>-1.52071</td>
</tr>
</tbody>
</table>

Note: Equal variances assumed using Levene’s Test for Equality of Variances with 95% level of confidence
* the difference is statistically significant with 95% confidence level

Students’ perceptions of the course

Students’ perceptions of the course were evaluated using the institutional end of semester SPOT survey. In the survey, students were asked to self-report their level of agreement with 10 different statements regarding students’ experiences with the instructor and the course. Students rated each question from 1 to 6 being 6 the higher level of agreement. In addition to the 10 quantitative questions, there were several open-ended questions where students could elaborate on their opinions about aspects of the course. For this paper purpose, I only considered the quantitative questions.

Figure 3 summarizes students responses to the different questions. In general, students perceptions of the course were better in the experimental group, in almost every question the difference is more than half a point. Also, students in the experimental group had on average a smaller standard deviation, meaning that their positive responses were more consistent. T-tests were also conducted and results are presented in table 3. The assumption of homogeneity of variances was tested and in some cases satisfied via Levene’s test and the level of confidence assumed was 95% (p=0.05). As can be seen in table 3, out of the 10 questions only 6 questions had statistically significant differences in the ratings. Students in the experimental group were associated with a statistically significant [t(28.99) = -2.165, p = 0.039] better perception of the instructor preparation M = 5.84 (SD = 0.36) when compared to the control group M = 5.25 (SD = 1.37). Similarly, when students were asked if the instructor
provided feedback intended to improve my course performance the experimental group had a higher agreement M = 5.57 (SD = 0.56) than the control group M = 4.96 (SD = 1.42), the difference is statistically significant [t(58) = -2.265, p = 0.027].

Figure 3: Students’ perceptions of teaching results

Table 3: Independent Samples T-test result for SPOT data

<table>
<thead>
<tr>
<th>Question</th>
<th>t</th>
<th>df</th>
<th>Sig. (2-tailed)</th>
<th>Mean Difference</th>
<th>Std. Error Difference</th>
<th>95% Confidence Interval Lower</th>
<th>95% Confidence Interval Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>The instructor was well prepared *</td>
<td>-2.165</td>
<td>28.99</td>
<td>0.039 ***</td>
<td>-0.58923</td>
<td>0.27218</td>
<td>-1.1459</td>
<td>-0.03255</td>
</tr>
<tr>
<td>The instructor presented the subject matter clearly *</td>
<td>-1.847</td>
<td>34.38</td>
<td>0.073</td>
<td>-0.55556</td>
<td>0.30083</td>
<td>-1.16667</td>
<td>0.05556</td>
</tr>
<tr>
<td>The instructor provided feedback intended to improve my course performance **</td>
<td>-2.265</td>
<td>58</td>
<td>0.027 ***</td>
<td>-0.61279</td>
<td>0.2705</td>
<td>-1.15427</td>
<td>-0.07132</td>
</tr>
<tr>
<td>The instructor fostered an atmosphere of mutual respect *</td>
<td>-1.777</td>
<td>30.103</td>
<td>0.086</td>
<td>-0.49832</td>
<td>0.28045</td>
<td>-1.07099</td>
<td>0.07436</td>
</tr>
<tr>
<td>Overall, the instructor’s teaching was effective *</td>
<td>-2.231</td>
<td>32.346</td>
<td>0.033 ***</td>
<td>-0.71717</td>
<td>0.32151</td>
<td>-1.37179</td>
<td>-0.06256</td>
</tr>
<tr>
<td>I have a deeper understanding of the subject matter as a result of this course *</td>
<td>-2.065</td>
<td>33.186</td>
<td>0.047 ***</td>
<td>-0.63869</td>
<td>0.30922</td>
<td>-1.26767</td>
<td>-0.00971</td>
</tr>
<tr>
<td>My interest in the subject matter was stimulated by this course **</td>
<td>-2.06</td>
<td>58</td>
<td>0.044 ***</td>
<td>-0.60606</td>
<td>0.29419</td>
<td>-1.19495</td>
<td>-0.01717</td>
</tr>
<tr>
<td>The objectives of the course were clearly explained **</td>
<td>-1.457</td>
<td>58</td>
<td>0.15</td>
<td>-0.36364</td>
<td>0.24955</td>
<td>-0.86316</td>
<td>0.13589</td>
</tr>
<tr>
<td>The out-of-class assignments were educationally valuable *</td>
<td>-3.209</td>
<td>35.08</td>
<td>0.003 ***</td>
<td>-0.84512</td>
<td>0.26339</td>
<td>-1.37978</td>
<td>-0.31046</td>
</tr>
<tr>
<td>The instructor related theories and concepts to practical issues *</td>
<td>-1.965</td>
<td>51.21</td>
<td>0.055</td>
<td>-0.3064</td>
<td>0.15592</td>
<td>-0.61939</td>
<td>0.00659</td>
</tr>
</tbody>
</table>
Equal variances not assumed using Levene's Test for Equality of Variances
** Equal variances assumed using Levene's Test for Equality of Variances
*** the difference is statistically significant with 95% confidence level

Overall, students in both group considered that the instructor teaching was effective. However, the experimental group was associated with a statistically significant \( t(32.34) = -2.231, p = 0.033 \) better perception \( M = 5.60 \) (SD = 0.60) when compared to the control group \( M = 4.88 \) (SD = 1.57). In terms of students perception of having a deeper understanding of the subject matter as a result of the course, students in the experimental group also reported a higher level of agreement than the control group (\( M= 5.48, \) SD= 0.66 vs. \( M= 4.84, \) SD= 1.46) that was statistically significant \( t(33.18) = -2.065, p = 0.047 \). A similar favorable result statistically significant for the experimental group is observed when students were asked if their interest in the subject matter was stimulated by the course (\( M= 5.27, \) SD= 0.91 vs. \( M= 4.66, \) SD= 1.35), \( t(33.18) = -2.065, p = 0.047 \). Finally, students in the experimental group considered with statistical significance \( t(35.08) = -3.209, p = 0.003 \) that the out-of-class assignments were educationally valuable \( M= 5.69 \) (SD= 0.58) when compared with the control group \( M= 4.85 \) (SD= 1.26).

Discussion

The purpose of this paper was to understand the impact that providing students with the opportunity to give continuous feedback had in their perceptions of the course. I conducted an experiment with an experimental group that was able to provide weekly feedback and a control group that did not have that opportunity. Changes to the course were made continuously based on the feedback provided. My results suggest that students that were able to provide feedback performed better overall when compared to the students that did not have that opportunity. In addition, students that were able to provide feedback had a better perception of the course as suggested on their final evaluation of the course through a SPOT survey. Although students in the control group performed considerably worse than students in the experimental group, their grades are similar to the typical average grades in this course.

As opposite, students in the experimental group performed considerably better than the typical average in this course, even when they were graded in the same way and by the same graders. Graders in the course (i.e. two undergraduate graders, the GTA, and the instructor) were randomly assigned to grade assignments from both sections, furthermore, graders did not know which section or student they were grading as every assignment was anonymized. I argue that students that were able to provide feedback were considerably more motivated in the course, hence, their performance was better. This aligns with Giesey et al. (2004) findings. In general, students grades from Module 2 were lower than the initial grades obtained in Module 1, historically this has been the case as Module 2 was about MATLAB programming and several students have problems with this topic. However, students in the experimental group started improving their grades in Module 3, instead, students in the control group continued to lower their grades in this module, obtaining a worst performance than in Module 2. I argue that students in the experimental group also increased their grades in Module 3 as at that point they were very engaged with the course, because students had been providing weekly feedback for more than half of the semester.

Regarding students perception of the course, students in the experimental group reported better perception in all the questions, however, the differences were only statistically significant in 6 of them. Interestingly, the questions where there was statistical significant difference were questions that could be associated to the students' opportunity to provide continuous feedback. For example, the question “The instructor related theories and concepts to practical issues” did not have a statistically significant difference, however the students perceptions on this topic would probably not been influenced by the opportunity to provide feedback, as feedback probably wouldn’t change the instructor ability to make connections between theory and practice. On the other hand, the students’ perceptions in the
question “The instructor provided feedback intended to improve my course performance” or “I have a deeper understanding of the subject matter as a result of this course” could be positively impacted by the students’ ability to provide continuous feedback.

On a personal note, I also was able to perceive a different energy and attitude from the experimental group. I have taught this course several years and the experimental group was the most engaged and enthusiastic group of students that I have had, I believe the fact that they could provide feedback and saw that I was making changes to the course based on the feedback did have a positive impact, they were continuously letting me know how much they appreciated the fact that I cared about them. Their enthusiasm was not only reflected in their good performance in the class, but they also participated in class and promoted deep discussions about different topics. In terms of effort, I did spend more time analyzing the feedback every week and preparing and adapting the course based on the feedback, however, the continuous feedback is a practice that I will implement in all my courses. I think the benefits of how engaged the students were and the quality of the work they submitted compensates for any additional effort, so I encourage instructors to start adopting this practice. Furthermore, I consider the feedback served as a measurement of my teaching effectiveness and made me change some of my pedagogical strategies and reflect on my teaching practices.

Future work

I plan to expand this research in several ways. First, I will analyze the qualitative data provided on the SPOT survey to identify if there are significant differences between students open-ended responses. Second, I plan to implement the continuous feedback system in all my classes at the undergraduate and the graduate level and I plan to conduct interviews with students at the end of the semester to better understand how they feel about having the opportunity to provide feedback. I also plan to expand my research to investigate alternative ways to evaluate teaching effectiveness.

References


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A strategy harnessing the power of cooperative learning suitable for problem-solving tutorials in mechanical engineering thermodynamics

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Abstract: We found that many students in the Thermodynamics class preferred to follow a passive approach towards their learning. Tutorial attendance was poor and many students complained that the lecturer did not do enough problems on the board. In an effort to alleviate the problem, we decided to develop an active teaching–learning strategy, incorporating the five elements of cooperative learning. After several iterations, we finalised a viable teaching–learning procedure called cooperative pair problem solving (CPPS) where students work together in groups of two during problem-solving tutorials. A sound theoretical framework based on the social cognitive theory of Bandura and informed by the social interdependence and social constructivist theories was developed. Using qualitative and quantitative measuring instruments, we found that the five elements of cooperative learning were successfully structured in the procedure and that it created a teaching–learning environment characterised by active learning and peer instruction, which was valued by students.

Introduction and background

Thermodynamics is often seen as difficult to understand, and the pass rate in the first introductory mechanical engineering thermodynamics module has generally been low. We felt that an important reason for this state of affairs was that many students preferred to follow a passive approach towards their learning, based on memorisation and reproduction. They often complained that the lecturer did not explain and solve enough problems on the board during contact sessions, and only a handful of students attended the problem-solving tutorials. Various active learning approaches have been proposed, many of which included some form of collaboration between students (Felder & Brent, 2016). The advantages of one such approach, cooperative learning (CL), over individualistic and competitive learning has been proved in numerous studies (Johnson, Johnson, & Johnson-Holubec, 2008).

Despite its proved advantages, CL is not implemented as widely as one would expect (Ahern, 2007). The reason may be a lack of (or even bad) experiences with group work, both as student and as lecturer (Ahern, 2007; Smith, Sheppard, Johnson, & Johnson, 2005). Also, implementation is not straightforward. Felder and Brent (2016) note the implementation of CL practices requires knowledge and proper planning. There may also be resistance from students. According to Baker and Clark (2010), students specifically do not approve of an uneven distribution of workload. Felder and Brent (2016) note that students tend to resist procedures where they are expected to take more responsibility for their own learning than what they are used to.

In the teaching of computer programming, a successful collaborative programming approach, pair programming, was developed (Williams & Kessler, 2003). This approach draws on the principles of pair problem solving as introduced by Lochhead (Whimbey, Lochhead, & Narode, 2013). Mentz, Van der Walt, and Goosen (2008) suggest that CL principles should
be incorporated into pair programming to render it a more effective teaching–learning strategy.

The purpose of this study was to develop a viable strategy for the problem-solving tutorials in the module Thermodynamics, based on pair programming (Williams & Kessler, 2003) and pair problem solving (Whimbey et al., 2013). We wanted the envisioned strategy to be based on a sound theoretical framework with the five elements of CL sufficiently structured in the procedure as we were convinced that that would ensure an effective teaching–learning environment valued by students.

**Theoretical framework**

According to Johnson and Johnson (2013), three perspectives have guided research on cooperation: perspectives on social behaviour, perspectives on the development of cognition, and perspectives on social interdependence. For this study, the three theories associated with these perspectives were the social cognitive theory (SCT), the social constructivist theory, and the social interdependence theory. These three theories are discussed next.

**Social cognitive theory**

The SCT emphasises that much learning takes place in a social environment. Furthermore, the SCT explains human functioning according to a model “in which behaviour, cognitive and other personal factors, and environmental influences all operate as interacting determinants of each other” (Bandura, 1986, p. 18). The desired behaviour is that the students should cooperate and help each other. Personal factors include visible aspects but also invisible aspects such as knowledge and skill. The learning environment has both a physical and social dimension (Radovan & Makovec, 2015). The social environment refers to the nature of the contact between the student and the lecturer as well as among the between students themselves (Fredericks, Fleming, Burrell, & Griffin, 2012).

The SCT formed the basis of the theoretical framework but was informed by the social constructivist and the social interdependence theories.

**Social constructivist theory**

According to the constructivist view, students are active participants in the learning process and select, re-interpret and re-organise information in order to give meaning to and make sense of this information and experiences, in other words, they construct their own knowledge (Ertmer & Newby, 2013). Social constructivism is associated with the work of Vygotsky (1978). He focused on the development of scientific concepts, that is, concepts that are first developed by society and then shared with children (Bächtold, 2013).

Two trends are distinguished in social constructivism. The first trend, enculturation, was described by Driver and her co-workers as “the process by which individuals are introduced to a culture by more skilled members” (Driver, Asoko, Leach, Scott, & Mortimer, 1994, p. 7). The second trend, cooperation, has its origins in the study of cooperation between children. During cooperation, the differences between children give rise to socio-cognitive conflict, which stimulates the development of the child’s cognitive structures (Bächtold, 2013). Goos, Galbraith, and Renshaw (2002) have shown that students help each other to solve problems successfully when they challenge each other’s understanding. This interaction creates a bi-directional zone of proximal development where students can coordinate their different perspectives.

**Social interdependence theory**

According to Johnson and Johnson (2013, p. 89), “[t]he basic premise of the social interdependence theory is that the type of interdependence structured in a situation determines how individuals interact with one another which, in turn, determine outcomes.” Interdependence can be positive or negative. Positive interdependence exits if there is a positive correlation between the achievements of team members (Johnson & Johnson,
In other words, we cannot succeed independently of each other; my success facilitates your success, and your success facilitates mine. According to Felder and Brent (2016), positive interdependence exists if team members have to rely on each other in order to be successful.

Cooperative learning

According to Johnson et al. (2008), in order for cooperation to work well, it is necessary to structure five elements explicitly into each cooperative session. These elements are positive interdependence, individual accountability, promotive face-to-face interaction, interpersonal and small-group skills, and group processing. The five elements of CL were structured in CPPS, which is discussed in the next subsection.

Methodology

The discussion of the intervention is followed by a description of the structuring of the five elements in CPPS. We felt that the structuring of the five elements in CPPS was necessary for the procedure to be successful.

The intervention

From the literature, it transpired that students often resist the implementation of CL strategies and that it is necessary to make a conscious effort to obtain their cooperation (Felder, 2007; Oakley, Felder, Brent, & Elhajj, 2004). Therefore, during the first class meeting with the students, three approaches to teaching (individual, competitive and cooperative) and the advantages of CL were discussed (Johnson et al., 2008). The procedure they had to follow during the tutorial was described and they were told how to form a working relationship with their partners.

The tutorials took place once a week in the afternoon. Attendance of the tutorials was voluntary. The accumulated average of the marks obtained during the tutorials was added to each student’s participation mark as a 5%-bonus. We kept the contribution towards the participation mark small because we wanted the primary reason students attended the tutorial to be the benefit they gained from attending: the activity of solving problems together.

The first step in the procedure as the students entered the tutorial class was group formation. Felder, Woods, Stice, and Rugarcia (2000) as well as Oakley et al. (2004) recommend that students should not be allowed to form their own groups, as students who know each other and are so inclined, are more prone to taking shortcuts. Therefore, a robust, traceable random group formation procedure using a PC and student cards was developed. It was possible to check whether students sat in their allocated places. Students who did not sit in their allocated places did not receive any credit for that tutorial. Once students realised that they could not cheat the system without consequences, they generally adhered to the arrangement.

Once students were seated, they wrote a short individual test covering the lecture content since the previous tutorial. The tests were taken in by the assistants (and marked afterwards.) The questions in the individual test were discussed with the class. This was followed by the discussion of a new social skill every week. The social skill discussed the previous week was also reviewed. The student assistants then handed out the tutorial problems – one copy per pair. Several synergistic measures were taken to promote cooperation. These measures are discussed later in the section on structuring the five elements in the design of CPPS. As they completed the problems, each pair submitted, by mobile phone, their student numbers and answers to the problems on a dedicated website. After the website had been closed, the approach and solutions to the problems were discussed with the whole class. This gave the students the opportunity to check their strategies and solutions. The problem statements as well as the intermediate and final answers were made available on the course website.
The design of CPPS

The structuring of the five elements of CL is discussed next.

Positive interdependence. The environment was manipulated to create conditions that would promote interdependence and encourage students to rely on each other. An important step was to make the problems sufficiently challenging so that the solution was not immediately obvious. Moreover, limited time was available to solve the problems. The goal was to make it advantageous for both partners to coordinate their understanding and mental efforts as well as to share resources and divide the different tasks between themselves. The two students sat next to each other (environmental interdependence) and each pair received only a single hard copy with the problems (resource interdependence). The two students had to provide a single answer for each problem (goal interdependence) and they were awarded the same mark for this joint effort (outcome interdependence).

Promotive interaction is characterised by students behaving in a certain way – they help each other or challenge each other’s understanding and strategies and accept co-responsibility for the success of the group (Johnson & Johnson, 2013). According to the social interdependence theory (Johnson & Johnson, 2013), positive interdependence will result in promotive interaction. In the first place, promotive interaction was therefore dependent on the strength of positive interdependence, the perception (a person factor) of students that it is necessary for them to rely on and help each other (behaviour).

Secondly, promotive interaction was also structured in the environment. These environmental variables targeted students’ behaviour directly, as well as their perceptions.

- During the first lecture period, the students were introduced to CPPS and the procedure explained and motivated.
- During the tutorial, questions from students regarding the problems were answered by involving both partners and facilitating a discussion between the two of them.
- During the tutorial, groups were monitored to ensure that they cooperated.
- The discussion of the problems at the end of the tutorial, gave students a final opportunity to explain and seek clarification from each other.

Individual accountability and personal responsibility. According to Johnson and Johnson (2013, p. 105), positive interdependence will create “responsibility forces” that will make team members feel more accountable and responsible to complete their part of the work and facilitate the success of other team members. An important environmental variable was the group size. One of the goals of using pairs was to make each member’s contribution (or lack thereof) easily visible and to strengthen the moral imperative to accept responsibility for the success of the group. Furthermore, students were not allowed to form their own groups as it would have made it easier for individual students not to contribute fully if they worked with a friend (Oakley et al., 2004).

Social skills. During the development of CPPS (Van Niekerk & Mentz, 2013), it became clear that students generally worked well together. This could be due to the small group size (Johnson et al., 2008), because well-defined procedures were used during problem solving and the fact that the problems generally only had one correct answer. It was therefore seldom necessary to debate the individual merits of two (or more) possible solution strategies. In spite of this, we decided to discuss group work skills as recommended by Johnson et al. (2008).

Group processing. New pairs were formed each week and a reflection on the functioning of each group during a tutorial was not formally structured into the procedure. However, students had the opportunity to reflect on their own application of those skills when group work skills were reviewed. The discussion of the problems and their solutions at the end of the tutorial also gave students an opportunity to reflect on their interaction and the effectiveness of their cooperation, which is another aspect of group processing (Felder & Brent, 2016).
The procedure described above was the end-result of several iterations. During the implementation of the finalised version, we collected empirical data to determine the extent to which the five elements of CL were perceived to have been structured in the procedure.

Locality and population

The study was performed at a South African university presenting a four-year degree course in Engineering. The university has faculties spanning a wide spectrum and more than 20 000 full-time students. The engineering qualifications are accredited by the Engineering Council of South Africa (ECSA), which is a signatory to the Washington Accord, the Sydney Accord, and the Dublin Accord. The first introductory thermodynamics module is taken in the second semester by second-year mechanical engineering students. Ethical clearance to conduct the research was obtained from the ethics committee of the university and informed consent was obtained from students who participated.

Research design

A convergent parallel mixed-methods design was used, employing quantitative and qualitative methods. To collect quantitative data, at the end of the semester, after experiencing CPPS, the students were asked to complete a questionnaire with seventeen Likert-type questions. For qualitative data, we asked two observers to attend one of the CPPS tutorials. The first author also kept a journal and conducted semi-structured interviews with the students in order to determine their experience of the CPPS procedure.

To determine the number of interviews, we considered the fact that the research took place in a single specific course. Of the 239 students on the class list, 96% were indicated as white and 92% as male. Furthermore, the goal of the interviews was to determine students' experiences of CPPS during a single event, namely the tutorials. All these factors indicated that a smaller number of interviews would be sufficient and it was decided to do seven interviews. This made it possible to randomly select and invite a representative number of male and female students for the interviews. While not required for the purposes of this study, in order to have the participants better reflect the demographics of the group, a student from the combined African, Coloured and Indian group was also randomly selected, invited, and interviewed. After the seven interviews, we were satisfied that data saturation had been reached and that it was not necessary to conduct any additional interviews.

As mentioned, the first author, who is also the presenter of the module, conducted the interviews. The interview invitation sent to students clearly stated that participation was completely voluntary and that not accepting the invitation, as well as anything said during the interview, will not lead to any form of discrimination against the student. Also, the interviews were held after the last tutorial and the conclusion of the lectures, after all assessment marks were finalized.

An interview protocol with several open-ended questions was prepared beforehand. The interviews were recorded, transcribed, checked by an external party and coded using ATLAS.ti. During coding, we used the elements of CL as a priori themes. The two observer reports were analysed in the same way.

In order to compile the Likert-scale questionnaire, it was necessary to adapt and reformulate questions from questionnaires found in literature, and to formulate a few new questions. Seventeen questions were formulated probing students’ perception of the implementation of the five elements of CL (Van Niekerk & Mentz, 2015). Students could indicate the extent to which they agreed with each statement on a four-point Likert-type scale with 1 indicating “Do not agree at all” and 4, “Fully agree”. A total of 163 questionnaires were completed.
Results and discussion

In this paragraph, we discuss the empirical evidence on how the structuring of the five elements of CL was perceived and experienced as well as the CPPS procedure as seen against the theoretical framework discussed earlier.

An evaluation of the success of the structuring of the five elements

The five elements are discussed separately.

Positive interdependence

Several interviewees mentioned how they coordinated their efforts. The following remark was typical, “I suggested equations that I knew would work, for which I knew the variables and then the other guy said yes, he agrees, or no he has other equations” [B4].

One of the observers wrote, “[a]n explanation by the lecturer of the problem-solution strategy or the solution to the problems was followed by intensive discussion between the members of the group, explaining the work to each other or trying to get clarity of what has been said” [OB]. The quantitative data obtained by means of the Likert-type scale indicated that students essentially agreed that positive interdependence existed. The average for the positive interdependence factor was 2.82 on the four-point scale.

Promotive interaction

When they received the hard copy with the problems, the students almost involuntarily turned towards each other and started reading. From the interviews, it was clear that students were willing – even eager – to share their ideas and discuss possible approaches to the problem with their partners. One student called it a “constructive thinking process” [B8].

They helped each other in different ways. They shared different perspectives, “[w]e first read the problem in silence and then we went through it together. Yes, just to say this is what I see and this is what the other person sees” [B4]. They also compensated for incomplete understanding, “[i]t often happened that you maybe cannot write down the mass balance and then the other guy will perhaps mention a small thing that will make you decide okay, let us try it” [B3].

Only one interviewee mentioned a big difference in preparedness between her and her partner, which made reciprocal promotive interaction impossible, “[w]ith the first tutorial, the guy who sat next to me only heard that day that he could take Thermodynamics, so he knew nothing about it. I had to show him every, every, everything” [B1]. It is clear that two forms of promotive interaction took place: a synergetic, reciprocal interaction (bi-directional help) as well as uni-directional help, when there was a difference in understanding, ability or preparedness between students. On the Likert-type scale, the average for the factor promotive interaction was 3 out of a maximum 4.

Personal responsibility and individual accountability

Environmental factors were manipulated to strengthen feelings of individual accountability and personal responsibility. One of the interviewees remarked, “[m]ost of the people who attend, actually wants to work, so I think that voluntary attendance, 5% bonus marks is a good thing because it keeps the guys who do not want to work away” [B1]. One of the observers remarked, “[i]t seems that most groups used the inputs from both members and that the group was not dominated by one person” [OB]. Working with strangers encouraged some students to put in more effort, “[y]es, you are out of your comfort zone and I think [working with a stranger] helps you to perform. If I work with a friend, if I cannot do something, it does not matter as much and you do not put in as much effort” [B5]. The average for the individual responsibility factor on the Likert-type scale was 3.
As can be expected, not all groups worked together equally well. Sometimes inter-group discussions took place, especially when the website was about to be closed. Sometimes an individual left the group to find help with another group, or approached the facilitators individually. We then accompanied the student back to the group and addressed the problem involving both students.

**Interpersonal and social skills**

Already during the development of CPPS, it was clear that students generally worked well together in a pair (Van Niekerk & Mentz, 2013). One of the observers remarked, “[t]he students’ group work skills are really good … most worked amazingly well together” [OA]. The student assistants played a role in conflict resolution, “[w]hen he thinks he is right and I think I am right, then it is very simple, we raise our hands and ask the lecturer: Is this right or that? And so you sort it out” [B3]. The average response to a statement in the questionnaire – “Conflict regularly occurred during CPPS” – was a low 1.55.

**Group processing**

Students could reflect on their own ability when group work skills were discussed and reviewed. It was clear that one student thought about this when he remarked, “[i]nitially when we heard how it is going to work, it was a bit strange but later we got used to it and it improves your people skills” [B6].

Students also reflected on the development of their problem-solving skills. When asked what contributed most to her understanding of the problems during the tutorial, one student said, “I would say the discussion afterwards, because sometimes you do not really understand the problem that you have done [during the tutorial]. When I had the most ‘AHA!’ moments was when we went through the problems afterwards” [B1].

During the tutorial, peer instruction dramatically reduced the load on the shoulders of the instructor. It was no longer necessary to answer trivial questions from many individual students as they cleared up many uncertainties among themselves. Only when it became clear that several groups struggled with the same concept, was it discussed with the whole class. These problems were usually difficult and it was therefore possible to pay proper attention to the explanation thereof. There was much activity between students as they read and discussed the problem statements, and solved the problems together. Even though attendance was voluntary and only bonus points were awarded, on average two thirds of the students on the class list attended the tutorials, which was a huge improvement compared to previous years.

**A theoretical framework of the CPPS procedure**

A explained before, the theoretical framework of CPPS is based on the social cognitive theory and informed by the social constructive and social interdependence theories. Using the empirical results to enrich the theoretical framework, the CPPS procedure can be presented graphically as shown in Figure 1 on the next page.

The manipulation of the environment played a crucial role in structuring positive interdependence, the most important element of CL (Johnson et al., 2008, p. 1:14). The goal of making the problems challenging and only allowing a limited time, was to strengthen the perception of each student that they could not succeed independently of each other, that they had to rely on each other and coordinate their efforts. According to the social interdependence theory, this positive interdependence resulted in promotive interaction where students cooperated and helped each other in two ways, namely providing synergistic bi-directional as well as uni-directional help. The enculturation aspect of the social constructivist theory was made possible by the presence of the lecturer and student assistants and the cooperation aspect of the social constructivist theory, by the presence of the other student in the pair. The end result was that students improved their problem-solving and social skills.
Figure 1. The theoretical framework of the CPPS procedure

Conclusions

We are satisfied that the empirical data indicated that the five elements of cooperative learning were successfully structured in the CPPS procedure. Ample evidence exists that an effective teaching–learning environment resulted, characterised by peer teaching and active learning, which dramatically reduced the load on the shoulders of the instructor. The fact that two thirds of the students on the class list attended the tutorials seems to be a clear indication that the students valued the opportunity to solve problems together with the aid – where necessary – of the facilitator and student assistants.

We are convinced that the fact that the students could not self-select their partners, underpinned the successful structuring of the five elements of CL. The importance of having an impersonal (in this case, a PC-based) mechanism available for group formation, and the ability to check whether students sat in their randomly allocated places, cannot be overemphasised. It meant that the facilitators did not have to check whether students sat in their allocated places and eliminated an important potential source of conflict between facilitators and students.

We found that CPPS is an easy-to-implement cooperative teaching–learning strategy suitable for large groups of a hundred students or more. Due to its sound theoretical basis, CPPS will most probably also be suitable for problem-solving tutorials in other engineering
science courses (or even pure science tutorials) and at other universities in those disciplines that follow a similar approach of lectures and problem-solving tutorials.

While the goal of the study was never to determine the perception of minorities as such, we found that an advantage of the random, rigid group formation procedure, was that students who were not part of a group, or might have felt excluded for whatever reason, just needed to show up and were allocated a partner with whom they could then cooperate in a comradely manner. This seems to indicate that CPPS should be equally suitable for more racially and gender diverse groups.

References


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Why lecturers in an engineering school assess the way they do

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Abstract: Shifting students’ learning behaviours to deeper levels of engagement is an ongoing challenge. Assessment practices have the potential to shape student learning by opening up opportunities for positively changing the way that students learn. Learning-oriented assessment theory provides guidelines for improving assessment practices, but it is not clearly understood how the principles that underpin this theory are interpreted in an engineering context. This study explores lecturers’ assessment practices in an engineering school where student success rates are frequently lower than expected. The purpose is to gain insight into the factors that influence lecturers’ choice and use of assessments and the perceived influence that assessments have on student learning. Results from interviews with ten lecturers reveal phenomena related to the constructive alignment of assessment criteria, feedback and learning outcomes specifically in the shift from traditional to project-based assessment.

Introduction

Higher education in South Africa is experiencing high student failure and dropout rates. Undergraduate engineering degrees are under particular pressure with completion rates in minimum time for a standard curriculum (4 years) of 23% and 41% of students graduating within five years (CHE, 2013). This occurs amidst an 80% increase in university enrolments since 1994 (CHE, 2013), funding challenges and institutions that are often under-staffed with pressure on academics to improve their research outputs (Badat, 2010). Students who fail their courses amplify the system demand as they have to repeat these courses, increasing class numbers even further. These capacity and funding constraints are not specific to South Africa with similar situations being reported in the UK and USA (Gibbs, 2006).

As student numbers increase, the time spent on marking and feedback increases which can result in academics spending more time on assessment than on teaching (Gibbs, 2006). As a consequence, large student numbers frequently influence the choice of assessment methods and potentially less assessment takes place with compromised or lower quality feedback. In extreme cases, courses may be implemented with no assignments, no written feedback or with feedback that is only provided after exams are written (Biggs & Tang, 2011).

Assessment practices are fundamentally linked to how students approach their learning (Prosser & Trigwell, 1999) and qualitative changes in student approaches have been shown to result in qualitative differences in the achievement of outcomes (Marton & Saljö, 1997). Shifts in teaching and assessment that occur under constrained conditions have the potential to influence student approaches to learning and have a significant impact on the ability of students to succeed. These shifts are also particularly likely to disadvantage weaker or marginalised students who require higher levels of feedback as they develop their learning strategies and refine their approaches.
Understanding how assessment shapes student learning

Assessment is central to facilitating a shift towards student-focused teaching and learning (El-Maaddawy, 2017) and is considered to be one of the most powerful ways to shape how students learn (Boud, 2007). It indicates what is valued in a learning context, “the backwash effect” (Biggs & Tang, 2011) and leads to the notion of the “hidden curriculum” (Sambell & McDowell, 1998) which suggests that it is what students view as important through their assessment lens that will influence what they do and how they do it. These approaches may not always be effective as some assessment tasks inadvertently incite less desirable learning strategies (Ramsden, 1979). The challenge is to ensure that what students are seeing and doing, as a result of the influence of assessment practices, aligns with the intended learning outcomes or what lecturers want the students to be doing and achieving.

Student learning approaches are typically classified as deep and surface (Marton & Saljo, 1984) and generally have two characteristics, the intent or reasoning behind the approach and the strategy or approach that is ultimately used (Entwistle, 1991). If students believe that they need to engage using deep approaches for a particular assessment task, they will try to do so, but if they believe they can do well without engaging, they will adopt surface or rote learning approaches (Bloxham & Boyd, 2007). The learning content and context can therefore determine students’ use of an approach, but it is often their perception of this context that influences how students learn (Entwistle, 1991). Students using an achieving approach (Biggs & Telfer, 1987), driven by a desire to succeed, will adapt their choice of approach (deep or surface), depending on what they believe will result in higher grades. Approaches to learning can also be affected by whether students feel alienated in their academic context which potentially leads to student disengagement from the academic process (Mann, 2001) although the nature of the curriculum and assessment tasks can play a role in addressing the extent of this sense of alienation (Case, 2013). Due to the critical and complex role that assessment plays in influencing student learning, understanding this landscape is key to unlocking the current challenges.

There have been many views on the purposes of assessment within the context of student learning. Summative assessment is traditionally viewed as assessing if students have met the required grade or intended learning outcomes (Chalmers & Fuller, 1996), providing access to other areas of the education system or the working world (Sambell et al., 2013). The need for summative assessment is often justified by the requirements of accrediting bodies that insist on evidence of how prescribed exit level outcomes are assessed (Rossiter, 2013). Summative assessment is however often criticised for its limited capacity to assess different learning outcomes such as higher order thinking skills (Green & Rollnick (2007) and reasoning and creativity (Knight, 2002). In contrast, the purpose of formative assessment is to develop and improve student learning where the tackling of the assessment task itself is the learning experience (Scott & Fortune, 2013). Formative assessment can, however, present its own challenges, as it often requires increased lecturer time (Chalmers and Fuller, 1996) and frequently results in a lack of student engagement (Rossiter, 2013) particularly if tasks are not for marks (Ramsden, 1992). Although traditional thinking believes that formative and summative assessment are distinctly different, implying that formative assessment supports student learning whereas summative assessment does not, it has been argued that in some cases formative and summative assessment can be interrelated (Sambell et al, 2013). Informal tasks (traditionally seen as formative) can be summated to provide input into final (summative) results and results from a summative task can be formative by providing feedback on learning (Fry et al., 1999). There is however general consensus that improved student learning is supported by a move from predominantly summative assessment practices to practices that incorporate formative elements and deeply engage students in assessment activities (Anderson, 1998 and Sambell et al., 2013). Due to the apparent difficulties in classifying assessment as formative or summative, thinking has evolved into perspectives that view assessment more holistically and consider the influence that assessment can have on student learning rather than the outcomes alone.
This thinking suggests a shift to learning-oriented assessment (Carless, 2007) with the focus on the learning that the assessment tasks illicit. Learning-oriented assessment can therefore incorporate traditionally formative or summative assessment types if designed and used with an underlying understanding that the purpose of assessment is to facilitate learning.

In learning-oriented assessment, the focus of students needs to be drawn away from the time allocated to assessment tasks (Scott & Fortune, 2013) and the associated marks (Bloxham & Boyd, 2007) to the process of learning. This requires increased student agency, moving away from a lecture-driven environment to one where the students themselves are required to play a much more active role. Feedback therefore plays a critical role as it supports the development of self-evaluative expertise (Sadler, 1989), enabling students to make informed judgements about the quality of their work. Student interaction with feedback needs to adapt from passive, mechanistic interactions to deeper and more reflective engagement that supports self-regulated learning as students experiment with different learning approaches (Scott & Fortune, 2013; Snyder, 1971; Nicol & MacFarlane-Dick, 2006). More than ever, this requires carefully planned and designed strategies to develop students in this process (Carless, 2015). This includes constructive alignment or congruence between learning outcomes, teaching and learning activities, assessment tasks and the criteria that are used to evaluate these outcomes (Biggs, 2014). Expectations of students should also be transparent, clear, consistent and high (Rossiter, 2013) so that they can be used to develop self-evaluation skills. Furthermore, this thinking requires the incorporation of authentic elements that develop lifelong learning skills (Boud & Soler, 2016), preparing students to meet the challenges of the workplace. Most of the required learning outcomes for engineering degree programmes are typically generic such as engineering professionalism, team and multidisciplinary working, independent learning ability and even engineering problem-solving skills. These generic outcomes can only actually be achieved if courses are aligned vertically through the degree programme. There therefore needs to be a consistent approach across the institution with a clearly defined philosophy throughout the degree programme and not only in individual modules or tasks (Lea & Street, 1998; Thomas, 2012). Ultimately, both a strategic and a scholarly approach (Scott & Fortune, 2013) is needed when adapting assessment practices to meet the changing needs of students, lecturers and the working world. Learning-oriented assessment requires a holistic change to the thinking of both students and lecturers and the paradigms that underpin teaching, assessment and the curriculum as a whole (Sambell et al., 2013) shifting the focus from the assessments themselves (a product centred approach) to the learning that takes place through assessments (a process centred approach), (Knight, 2002).

Historically, assessment in engineering contexts is typically oriented to establishing competence and is often criticised for incorporating insufficient formative assessment practices while providing limited feedback or feedback that centres on grades (McDowell, White & Davis, 2007). Although it has been shown that the engineering faculty supports the view that formative assessment and feedback is necessary and valuable, there are a variety of challenges including large class sizes, motivating students to participate, opportunities for cheating and collusion and limited experience in experimenting with alternative approaches (McDowell et al., 2007) that constrains major shifts in assessment for learning practices.

**Purpose and context of this study**

If assessment practices are to change the way that students learn, it is pertinent to understand firstly what influences current practices. The purpose of this study is to gain insight into assessment practices through the experiences and perceptions of lecturers. This study takes place in a School of Mechanical, Industrial and Aeronautical Engineering. The School experiences high undergraduate student failure with completion in minimum time of less than 8% and dropout rates of 60% over the degree (School of Mechanical, Industrial and Aeronautical Engineering, 2017). Failure rates are not confined to first-year students which suggests that the transition from school is not the core reason for the lack of student
success. Poor student performance is compounded by increased student intake that has resulted in very large class sizes, constrained resources and a variety of internal and external pressures. This results in a system with increasing demand and decreasing capacity which has the potential to significantly impact the academic practices and experiences of learning-oriented assessment in the School. This paper forms part of a more extensive study that also considers student experiences of assessment using a survey (Hattingh, Dison & Woollacott, 2019) and focus groups to gain a more vibrant picture of the assessment environment, triangulating data and evaluating the relationship between assessment practices and student learning behaviours. This study facilitates a broader conversation on the use of assessment in engineering contexts to enable improved student learning and ultimately higher levels of engagement and success.

Methodology

Students’ learning approaches are influenced by their prior learning experiences (Biggs & Tang, 2011) and current perceptions of their learning context (Prosser & Trigwell, 1999). For this reason, this study focuses on assessment practices across the degree programme capturing a holistic view of how experiences in courses influence concurrent or future courses as student approaches to learning develop. Semi-structured, individual interviews were conducted with ten (out of a total of 30), purposively sampled lecturers in the School to explore thinking beyond what might be obtained from a survey. Lecturers were asked approximately ten (based on the need for further probing) open-ended questions designed to explore their perceptions and experiences of: the overall purpose of assessment; factors that influence the design of assessment tasks; explicit and implicit criteria used to design and evaluate tasks; communication of expectations and criteria to students, feedback, experiences of student engagement with tasks, how well assessments actually evaluate the intended outcomes and how assessment could be improved. Interviews took place in a quiet and private location chosen by the interviewee, were 45 to 60 minutes in length, took place over a period of three months and were transcribed and analysed using a learning-oriented framework (Carless, 2015). The interviewed lecturers teach a range of courses across all four years of study including subjects such as mechanics, engineering drawing, mechatronics, engineering design and laboratory courses and complementary courses such as business management. The teaching experience of lecturers ranged from less than two years to more than 20 years which is representative of the teaching staff in the school and was purposively considered due to the range of experiences and perceptions that this could elicit. None of the teaching staff have any formal teaching qualification although some lecturers have attended short teaching and learning workshops through the University – this is also representative of the teaching profile in the School. The range of class sizes is from over 200 students for eight of the lecturers to less than 30 students for two of the lecturers.

Results

This section begins by presenting lecturers’ perceptions of the purpose of assessment and an overview of assessment choice. These topics provide a good context for interpreting the balance of the results. This is followed by key findings under the topical categories of expectations, criteria and feedback practices and experiences when shifting to project-based assignment tasks. The discussion thereafter presents a summary of the main findings and implications for the study.

Purpose of assessment

The interviews revealed that most lecturers design and use assessments with the intention of determining whether a student is ready to pass a course, ultimately to establish if they are ready for the working world or the next year of study. Lecturers elaborated on the evaluation of competence in identifying if students can demonstrate a deep understanding of course material and the ability to apply concepts to new or unseen problems. A theme that
emerges while considering lecturers’ conceptions of the purpose of assessment is where the agency or responsibility lies for the competence that is being determined. It is interesting to note from two of the descriptions given by lecturers that the focus is on understanding the concepts that have been “taught” or “covered in class” rather than what has been learnt by the students. Although subtle, this does suggest a particular lecturer mindset that aligns with a lecturer-centred approach to teaching and learning. The role of developing understanding is placed in the sphere of control of the lecturer rather than with the student (Gibbs, 1995) and the target is what the lecturer has covered rather than what the student has achieved through the learning process (Biggs, 2014). The findings also frame competence in terms of a rigidly defined course content allowing little scope for developing the students outside of what happens in the classroom and suggests that understanding is centred around the content or the product of the understanding rather than the process of understanding and the development of lifelong learning skills. Although competence is primarily determined in summative assessments such as tests and exams, more continuous assessments that take place throughout the semester, such as tutorials or assignments are also used. The purpose of these continuous assessments is often seen as a means of “forcing” students to keep up to date with course material throughout the semester, with lecturers similarly taking responsibility for the learning. Continuous assessments are also used to provide direction to students, giving them (predominantly through marks) a sense of whether they are on the right track. In extreme cases, lecturers indicated that tasks can be intentionally used as a "wake-up call" or to “scare” students into working consistently towards final exams. Although there are indications that assessment is sometimes used as a learning opportunity, the predominant thinking is framed by the assessment of learning paradigm in which student competence is guided by and determined by the lecturer.

**Choice and design of assessments**

The frequency of assessment types used by the interviewed lecturers is shown in Figure 2, with most courses using at least three different types of assessment. Formal low-stakes assessments are classified as tests that take place according to a schedule, during the semester, and count typically 25-30% towards the course mark. Formal, high-stakes assessments are traditional exams (typically 3 hours in length) that take place in a session at the end of the semester and count 50-70% of a course mark. Tutorial sessions usually occur weekly and are used to supplement lectures, where assistance is available to work through problems. Tutorials are mostly formative and voluntary but can include spot tests to “motivate” students to attend. Assignments or projects run over a number of weeks (usually 4-6), are often open-ended and require students to apply and integrate thinking and techniques from the course (or in some cases, several courses). These assignments can be individual or group projects and count up to 20% in courses that include tests and exams to over 50% in courses that have reduced or eliminated formal assessments such as exams. All lecturers who continue to use exams indicated that their motivation for choosing this type is because of the way that assessment has always been done. Some lecturers also indicated that they were not aware that it was not a requirement to have an exam. When designing both formative and summative assessments, lecturers mostly focus on testing understanding with an emphasis on finding ways to assess students in a way that discourages rote learning. However, most lecturers feel that current assessment practices (particularly tests and exams) are not achieving this purpose and are not shifting students to higher levels of thinking. This is evident particularly in courses where students can practice and learn methods for solving predominantly mathematical problems using surface, procedural approaches (Case & Marshall, 2004). Although lecturers admit that current assessments are not optimal, they indicate that they find it difficult to think of alternative ways of assessing whether students understand. Responses that illustrate this include:

“…well its tricky, if they follow the method and they do everything right…I probably wouldn't be able to know whether they know nothing or whether they know everything…”
“...the ones who've managed to memorise enough of the solutions are the ones who end up passing. So I don't think the exams are even serving their purpose…”

When designing assessments, although some lecturers argue that group skills are important, there is an underlying perception that students need to be assessed individually. This need sometimes results in contrived and counterproductive assessment practices. For example, most lecturers complain that students do not see the bigger picture despite students being forced to complete sub-sections of a design report individually to prove that each student is competent. Responses similar to the following interview extracts were expressed by several of the lecturers who make use of group projects:

"...even though it is a group report, I try to put in a little bit of individual assessment... I'll say, okay, at least each person must have a portion... that they have written themselves. So it shouldn't be a group collaborative effort for the whole... So...each person must develop ten percent..., and then I will assess them individually on that... because each person has to be competent...each person has to be competent.”

“...the individual assessment is still a test type... If I could get rid of that I would, but...the only reason I do it is because I need to still assess them as individuals, and if I don’t make it in test conditions then I don’t get the individual assessment, and I need to think about ways to get around that.”

Figure 2 – Types of assessment used by lecturers

Lecturers noted a variety of constraints that influence assessment decision making. The most significant, identified by eight lecturers, is class size. Large class sizes impact on marking time, group sizes, feedback, capacity for one-on-one consultations and laboratory equipment. Another significant constraint identified by some lecturers is the high workload placed on students and the amount of time that they have to work on different courses and assessments. Lecturers perceive that a lack of time management skills compounds the volume of work that students are required to complete, resulting in them prioritising some assessment tasks over others. Lecturers also believe that this affects the extent to which students are able to reflect on the learning process often resulting in sub-optimal approaches. When asked to comment on why students memorise instead of understanding, one respondent indicated:

“...they're trying to do what they can in the time that they've got and maybe the thinking gets lost because they don't have time to think and reflect.”

The predominant, high-stress exam environment is believed to exacerbate poor reflection:

“...students are not in a reflective state of mind when they're writing exams

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Other constraints include plagiarism, poor lecture attendance and a lack of student curiosity and willingness to “go beyond what is required”. All of the identified constraints influence lecturers’ design of assessment tasks and the extent to which they are able to engage students successfully in deeper approaches to learning.

**Expectations, criteria and feedback**

The majority of lecturers found it challenging to articulate the criteria they use for assessing learning outcomes. Although expectations for a course can be communicated in broad terms, lecturers say they are not able to identify the key outcomes that students need to fulfil to thrive in a course. They also describe how students struggle to come to terms with what is required for a particular task, causing frustration for both staff and students. Some lecturers revealed that when students do ask for clarity regarding what is required, it is difficult for them to articulate to students how they should navigate their way through the learning process. As expressed by one lecturer,

“…students ask: your course is tough, how can I pass this course? And even though I get asked this a lot of times, I always struggle to answer it.”

It appears that the confusion around assessment tasks is sometimes related to limited lecturer engagement with the criteria associated with tasks and by implication a lack of clear expectations that are communicated to and understood by the students. It was also evident in some interviews that lecturers communicate the criteria or outcomes for their course by describing what it is that the “product” or output of the assessment task is supposed to look like. For example, if students are required to design a particular mechanical device, lecturers describe achievements of a “good student” by how well the device performs according to a set of design specifications but struggle to explain what outcomes the student needs to have achieved in order to design the device. When asked how a student is assessed: “…has it achieved certain aspects of the task...” – where it refers to the product that was being designed rather than the understanding of the student. There is limited awareness of the skills that students need to acquire to get to the end point.

For all assessment types, there was little evidence of feedback. Most lecturers provide feedback to students by highlighting common mistakes in a general forum through an online learning platform or in-class lectures. There is strong evidence of a “show and tell” approach where lecturers tell students what was lacking without describing the process of learning to develop the necessary skills and abilities. Some lecturers describe feedback practices as:

“…what I do after a test, I have a session with them … and say, today we are now going to go through the test, I give them the question paper because we remove the question paper…and then these are the answers … I also point out the tricky areas.”

“I upload their marks…and one of the head tutors puts together a feedback form, like pages of feedback for each spot test that they’ve written, so common mistakes…if they read it…”

The lack of feedback is perhaps not surprising given the large class sizes, but more importantly, it is not surprising considering the extent to which lecturers understand what needs to be done to complete assessment tasks. This gap makes it very difficult for a lecturer to provide feedback because although they know that the student has not demonstrated competence or the required outcomes, they cannot always articulate what needs to change in the students’ learning process in order to move towards achieving these.

**Shifts towards project-based assignments and rubrics**

The majority of the interviewed lecturers (seven) have made significant changes in their assessment practices in the last two years. Many of these changes include a shift away from exams and tests towards project-based assignments. Some of the justifications for changing assessment practices include:
“...to make assessments more fair and better related to more real-world type assessment scenarios.”

“.we’ve gotten rid of the tests and exams ... it doesn't actually test them - projects are a better way of evaluating them.”

This shows a willingness, on the part of the lecturers, to shift assessment practices in a way that improves student learning. Most interviewed lecturers agree that assignments are better aligned with assessing student understanding and are more representative of real-world scenarios. Lecturers who have not made changes cite plagiarism and the need to assess individual competence as factors that constrain them. It is worth noting that although there is a shift away from formal assessments, often the justification is based on “evaluating them better”, the focus remains on assessment of rather than for learning.

The introduction of open-ended assignments has required a change in how assessments are marked and how expectations are communicated to students, resulting in the introduction of assessment rubrics. The purpose of rubrics is to enable what lecturers refer to as “objective” marking, ensuring consistency when marking large numbers of assignments. As a result, the rubrics have a high level of detail, with what could be considered method steps and mark allocations per step. Unfortunately, there is a perception that the rubrics seem to be driving student behaviour in the wrong direction, with lecturers complaining that students are merely “tick-boxing” elements of assignments without seeing the bigger picture, links or the purpose and intention behind elements in an assignment structure. It is as though the gains intended by moving away from exams and tests, are being lost due to the way that rubrics are being implemented. The following interview extract shows the apparent misalignment between the constraints that lecturers describe and the tools that are being used as part of the assessment practices:

“...the majority of students give me exactly what they’ve been given...about ten percent would give me something beyond that.” And yet, for the same respondent answering a question to why they think that students do not go beyond:

“...I do give them a nice breakdown of, you know, …it must address these points...”

It appears as if lecturers do not fully appreciate the influence that assessment practices have on student learning behaviours. Assessment practices, and rubrics, in particular, are not being used to develop students’ self-evaluative expertise or their engagement and development of sustainable learning skills.

Discussion

The findings suggest that there is an underlying consensus on the dispositions, behaviours and abilities that students need to acquire throughout their degree and that these outcomes require students to operate at higher levels of thinking (Biggs & Collis, 1982; Bransford et al., 2000). Despite these expectations, many issues identified by lecturers suggest that students are operating at lower levels of learning (Biggs & Collis, 1982). Students may show an understanding of content, but they are often unable to 'conditionalize' the knowledge by showing why or under what conditions the knowledge applies (Bransford et al., 2000) or how it can be related to other contexts or extended in abstract ways (Biggs & Collis, 1982; Crawford et al., 1994). Students are also perceived to adopt mechanistic approaches that focus on getting marks rather than conceptual understanding. Many challenges emerged from the study regarding lecturers’ conceptions of the role of assessment in student learning. There was general agreement that the purpose of assessment is driven by the need to establish competence and high stakes summative assessments remain the predominant methods used in the School despite obvious and acknowledged shortcomings in achieving the desired outcomes. These methods persist partly due to the historical way that they have been conceptualised and implemented but also because there is a lack of experience and exposure to alternative methods. The lecturers’ ability to articulate the intended learning
outcomes and criteria for courses is also limited and as a result, communicating expectations to students and providing feedback is difficult. Criteria often centre on the product of assessment tasks rather than the learning processes involved and feedback is therefore more diagnostic than showing students how to bridge the gap (Boud & Molloy, 2013). Despite the predominance of high stakes assessments, there has been a move towards project-based assessment. Rubrics have been implemented to provide more explicit expectations and feedback but these appear to be poorly designed and often lead to procedural and tick-boxing approaches which are counterproductive to the motivation for introducing these assessment tasks. Most of the changes to assessment also continue to place the onus on lecturers with limited transfer of the responsibilities of learning onto the students, limiting options for developing student self-regulation skills. The results suggest that despite an obvious willingness to influence student learning through assessment practices, there appears to be a lack of a systemic and holistic approach which results in ad-hoc use of pedagogical tools and techniques and independent and misaligned changes in courses throughout the degree programme. Lecturer agency is also adversely affected by a lack of awareness and confidence in teaching and learning as a discipline. The findings have provided insights into the powerful role that assessment can play in influencing student learning approaches and how valuable and important an understanding of lecturers’ perceptions and experiences is when aiming to improve student learning. The drivers and motivators behind assessment choices and the structural and educational constraints that lecturers face can influence how assessment plays out in a particular context, often in ways that are not anticipated. There is a clear need for deeper lecturer engagement with assessment theories and a more intentional and strategic approach to assessment in the School in order to improve student success through the assessment landscape.

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A comparative study to predict students’ performance based on their access pattern to the Learning Management System using an efficient Machine Learning Algorithm

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Abstract: Student performance plays a major role in educational institutions. Improving their performance will benefit the institution and students as well. We focus on predicting the students’ performance based on their past academic access pattern to the course materials on the Learning Management System (LMS). We employ one of the most efficient classification algorithms to perform this task. The algorithm can forecast the final grade and identify students who are at risk of failing the class. For this work, we made use of student data from Blackboard (Bb) Learn which is the LMS used at George Mason University (GMU). We gathered student’s past data and analysed several predictors that would contribute to the final result. The primary goal of this study is to verify the accuracy of the prediction algorithm by comparing the analytical results we get from our prediction model to actual students’ results. This study stands unique since we try to verify the results we get in a practical way.

Introduction

Educational Data Mining (EDM) is an emerging field in which educational data is investigated to better understand the students and their environment. It makes use of data mining techniques and machine learning algorithms to gain insights about students’ learning process. This can assist several educational institutions to fully understand students’ behavior by which they can adopt in betterment of the students and their future.

In our study, we use the educational data that is collected from Blackboard Learn, the learning management system (LMS) used at George Mason University. Blackboard is used by instructors and students to deliver and access the course content which includes course materials, discussion boards, home and lab assignments. The data that we use has information about every student’s navigational behavior. For instance, the number of times each student had access to a particular course item and the total time they spent on it. We explore these behaviors from the previous semesters to make predictions about current students, so that we can prevent them from failing a class or help them improve their grades. For example, based on the prediction data we can identify the students who would need to prepare harder for the upcoming midterm exam and lab skills exam 1 so that they may do well in those mid-semester heavily weighted assessments. The generalized predictions made by the algorithm are applicable for lecture and hands-on lab exams because the navigational behavioral data is based on access to lecture slides, recordings, lab and homework assignments, and reference materials that are very important for the students to prepare for these exams. Similarly, the training model would be useful to determine the
students at risk of failure prior to the final exam and lab skills exam and alert those students in advance to avoid a poor grade in the course. We use Support Vector Machine (Kuhn & Johnson, 2013) which is a supervised machine learning algorithm to build the mentioned training model. After building the model, we compare the observed grade (actual grade that we have access to) and the predicted grade (analytical result).

We try to answer the following research questions through this study:

- What correlation exists between the way students access the course material and their final grade?
- Can we identify students who are at risk of failure with accurate results using a machine learning algorithm?

**Literature Review**

The literature review concentrates on previous research and studies done on predicting students’ performance to determine which factors lead to student’s success. The study by Shahiri et al. (Shahiri, Husain, & Rashid, 2015) performed analysis on predicting students’ performance where they used CGPA and internal assessments as their datasets. Classification algorithms like Neural Network and Decision Tree were highly used to perform the analysis.

Several classification methods were used in (Bidgoli, Kashy, Kortemeyer, & Punch, 2003) to segregate students based on 3 cases. First one classifies students based on their GPAs into 9 classes which are 0, 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, and 4.0. In the second case, they classify students into 3 classes which is high for grades greater than 3.5, middle for grades between 2.0 and 3.5, and low for grades less than 2.0. The third case classifies students into 2 classes i.e., pass for grades greater than 2.0 and fail for grades less than 2.0. Multiple classifiers were used to improve the accuracy in all three cases. This study effort was done to predict the students’ final grades based on the features extracted from their homework data.

Naïve Bayes was found to be the most appropriate algorithm in (Kotsiantis, Pierrakeas, & Pintelas, 2004) according to the accuracy and sensitivity of the model. Six Machine Learning algorithms were used to identify poorly performing students in a distance learning environment of Hellenic Open University. The attributes used for their study included sex, age, occupation, marital status, computer literacy, written assignments, etc. Kabra and Bichkar (Kabra & Bichkar, 2011) used Decision tree classifier as an application of educational data mining to generate a model which is used to predict the students’ performance in the first year of their engineering exam. This is done to identify students who are likely to fail. Factors like gender, math or science score, location, parent occupation, etc. were also considered as input variables. Devasia et al. (Devasia, T P, & Hegde, 2016) made use of Naïve Bayes algorithm to predict the performance of students at the end of the semester. They used the same factors as gender, location, annual income, parental occupation, parent qualifications, reading habits, number of hours spent on studies, student grades in previous schools, social network usage, etc. They also made use of class test, seminar and assignment marks for predicting the output variable which is classified as poor, average, good, and excellent. One study by Sorour et al. (Sorour, Luo, Goda, & Mine, 2015) analysed the students comment data after each lesson to predict students’ grades.

Another study by Ashenafi et al. (Ashenafi, Riccardi, & Ronchetti, 2015) uses peer assessment system where students are required to participate in peer-based online homework activities throughout the course. There are several factors that were considered including tasks completed, voting and ratings of questions and answers discussed during the course, etc. Support Vector Machine was the most appropriate classifier in the study by Brodic et al. (Brodic, Amelio, & Jankovic, 2018) where first test grade, second test grade, attendance, seminar grade and final exam were used as the important features for the
model. The study is about the different classification techniques which can be used as a prediction tool in the education context.

Our previous research study (Damuluri, Ahmadi, & Islam, 2019) tries to analyse the most appropriate algorithm to predict the students’ grade. It was found that, SVM has better ability to predict the grade when compared to the other algorithms like Naïve Bayes, K-Nearest Neighbor, Linear Discriminant Analysis.

This study focuses on the navigational behavior of students on an e-learning platform. The model is trained on the students’ data accessing the course content which can be utilized to predict the students who need help with academic achievement. The institutions, educators and instructors can make use of these results to efficiently manage the course content. We consider factors like number of hours each student spent on the course or specific day of the week, total number of hours spent on the course, total logins, number of times and number of hours spent on each course item.

**Our Work**

**Method**

This study is based on the students’ data who enrolled in IT 341- Data Communications and Networking Principles and CYSE 230 - Computer Networking Principles courses in Volgenau School of Engineering at George Mason University (GMU). The main objective of this study is to verify the accuracy of the classification algorithm used in our analysis by comparing the analytical results we attain from the prediction model to the actual student results. The following sections describe each step performed in our analysis.

**Data Collection**

The data was collected from Blackboard. It consists of 300 student’s data from 11 sections of two identical networking courses. In Figure 1, we see the snapshot of a student’s excel file that was extracted from Blackboard. For each student, we have extracted such files and aggregated them to a single Excel file which contains all students’ data as shown in Figure 2.

![Figure 1. Snapshot of a student Excel file data](image_url)
After the data collection was complete, R Studio was used for further analysis where the file with extracted data is imported into R Studio.

Data Analysis
The first step after data collection is data pre-processing. Pre-processing must be performed to any data set to ensure it is clean and consistent which improves the training model’s performance. The missing values should be removed in order to achieve unbiased results. We used Mean Imputation Method (Buuren, 2018) to eliminate the missing values in the dataset. In this method, missing values in each variable are replaced with the mean of the corresponding variable. The variables which were considered for the analysis are shown in Table 1.

Table 1: Variables considered for the analysis

<table>
<thead>
<tr>
<th>Attribute Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sunday-Saturday</td>
<td>Time spent on a particular day</td>
</tr>
<tr>
<td>Total time</td>
<td>Time spent on the course</td>
</tr>
<tr>
<td>Total logins</td>
<td>Total number of logins</td>
</tr>
<tr>
<td>Total items</td>
<td>Items accessed</td>
</tr>
<tr>
<td>Ch1-Ch11 (Duration)</td>
<td>Time spent on each chapter</td>
</tr>
<tr>
<td>Ch1-Ch11 (Clicks)</td>
<td>No. of times each chapter is accessed</td>
</tr>
<tr>
<td>RS1-RS8 (Duration)</td>
<td>Time spent on Routing and Switching chapters</td>
</tr>
<tr>
<td>RS1-RS8 (Clicks)</td>
<td>No. of times Routing and Switching chapters are accessed</td>
</tr>
<tr>
<td>HA1 &amp; HA2 (Duration)</td>
<td>Time spent on Homework Assignments</td>
</tr>
<tr>
<td>HA1 &amp; HA2 (Clicks)</td>
<td>No. of times Homework Assignments are accessed</td>
</tr>
<tr>
<td>LS1-LS12 (Duration)</td>
<td>Time spent on each lab session</td>
</tr>
<tr>
<td>LS1-LS12 (Clicks)</td>
<td>No. of times each lab session is accessed</td>
</tr>
<tr>
<td>Grade</td>
<td>Student course grade</td>
</tr>
</tbody>
</table>
The variables in Table 1 are considered since they represent the time spent by students on the course study materials covered in the mid-term and final examinations, and lab skills exams. Mid-term and final exams are worth 40% and two lab skills exams are worth 20% of the course grade. For the analysis, we assume students utilize their time on blackboard effectively.

We build a training model to predict the outcome by using the variables mentioned in Table 1. Before building this model, we need to find the correlation between these variables and eliminate those which are negatively correlated with the final grade variable. Figures 3, 4, and 5 show the correlation between the variables.

Figure 3. Correlation plot for days of the week

Figure 4. Correlation plot for chapters
The correlation plots illustrate the relation between two variables. Blue color shows a positive correlation and red color denotes a negative relationship. In Figure 3, final grade has a positive correlation with Monday. This can be interpreted as a strong relation between the time a student spent on a particular day and the grade. With respect to the courses we considered, students spend more time on Monday since it is the due date for submitting most of the assignments.

From Figures 3, 4 and 5, we can observe that Final Grade has a positive relationship with most of the variables except for Wednesday and Chapter 10. This indicates that students have to concentrate on all of their coursework to obtain a good grade. To make our model perform better, we eliminate the two negatively correlated variables i.e., Wednesday and Chapter 10. The correlation plots help in selecting the Variables that contribute most to the final grade.

The dataset is now divided into training dataset and test dataset where training data represents the data used to train the model and test data represents the data used to validate the model. The classification model we use is the Support Vector Machine (SVM). We consider SVM since the accuracy of this algorithm was better than the other algorithms like Naïve Bayes, K-Nearest Neighbor, Linear Discriminant Analysis which was concluded from our previous research (Damuluri, Ahmadi, & Islam, 2019). The algorithm classifies the data points even in extreme conditions. We use this algorithm since it works well with small datasets which means it gives better accuracy when the dataset is small. The result of our analysis is the course grade of the student which has been classified as A, B, C, D and F.

Results

Table 2 depicts the results of our analysis which is the observed value (actual results) and the predicted value (analytical results). The output of our result is the student grade which ranges from A, B, C, D and F. The accuracy of prediction is determined with the function in R Studio which was found to be 70.21%. We can interpret this as following: out of 10 students, the algorithm is able to predict the actual grade of 7 students correctly, but it fails to predict the actual grade of 3 students. Since this is an ongoing study, there is scope to improve the prediction performance with more data in the future in order improve accuracy further.
From Table 2, we can see that the algorithm is able to classify the grades of A and B correctly and it’s not able to identify the grades of C, D and F accurately. This is because the data has small number of C, D and F grades and the model is not trained properly with respect to those grades.

**Table 2: Comparison of observed and predicted grade**

<table>
<thead>
<tr>
<th>Observed Grade</th>
<th>Predicted Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>C</td>
</tr>
<tr>
<td>2</td>
<td>B</td>
</tr>
<tr>
<td>3</td>
<td>B</td>
</tr>
<tr>
<td>4</td>
<td>A</td>
</tr>
<tr>
<td>5</td>
<td>C</td>
</tr>
<tr>
<td>6</td>
<td>B</td>
</tr>
<tr>
<td>7</td>
<td>A</td>
</tr>
<tr>
<td>8</td>
<td>A</td>
</tr>
<tr>
<td>9</td>
<td>F</td>
</tr>
<tr>
<td>10</td>
<td>B</td>
</tr>
<tr>
<td>11</td>
<td>A</td>
</tr>
<tr>
<td>12</td>
<td>C</td>
</tr>
<tr>
<td>13</td>
<td>A</td>
</tr>
<tr>
<td>14</td>
<td>B</td>
</tr>
<tr>
<td>15</td>
<td>B</td>
</tr>
</tbody>
</table>

**Conclusion and Future work**

Support Vector Machine was used as the supervised machine learning algorithm which can be used to predict the student’s final grade in the course. The algorithm is able to identify students who are at risk of failure with an accuracy of 70.21%. This can assist the instructors and the institutions to caution these students prior to the mid-semester and final exams to minimize actual failure rate. Moreover, the data would be useful for the instructors to better design their course content to help students focus on most important and related areas to prepare for the highly weighted assessments such as theoretical and lab exams.

The data is not normally distributed since it contains larger number of students with grades A and B and fewer students with grades C, D and F. The accuracy of the prediction can be improved if we have a dataset which is normally distributed i.e., same proportion of all the grades. In the future, we plan to include a larger dataset that may normalize the dataset which can further improve the accuracy and predict all of the grades more precisely. Also, we can include several courses other than just the networking courses.
References


Background and Design of a Qualitative Study on Globally Responsible Decision-Making in Civil Engineering

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Abstract: Organizations that regulate civil engineering have been pressing for integration of ‘global responsibility’ into higher education curricula since around 2006, with a goal of achieving environmental sustainability and social justice. In an effort led by the American Society of Civil Engineers (ASCE, 2007, 2009), a global vision for civil engineering was identified. Within the UK, the Institution of Civil Engineers (ICE) has been leading the way alongside non-governmental organizations (Bourn & Neal, 2008). Via the in-progress study reported here, a UK-based research team is now studying the effects of ACSE and ICE initiatives. Findings will hold value for the global community, as achieving sustainability is crucial to humanity, and indeed all life on Earth.

Introduction
Today, a university-based engineering education research team in the United Kingdom is partnering with Engineers Without Borders UK (EWB-UK) to conduct an exploratory study on engineers’ perception of global responsibility with regard to engineered environments. This topic was proposed for study by Engineers Without Borders UK, with a long-term objective of achieving globally responsible decision-making across engineering fields. Findings will hold value for the global community, as achieving sustainability is crucial to humanity, and indeed all life on Earth. This paper describes the team’s work-in-progress and serves as an example for other researchers regarding how to design similar projects in their own contexts.
The project is founded in the belief that environmental and social sustainability must be embedded into engineering education and engineering practice such that engineers can make better decisions day-to-day. This exploratory study grew out of three preliminary questions raised by EWB-UK: (1) To what degree are environmental, economic, and social sustainability valued in the practice of engineering? (2) To what degree are the values of environmental, economic, and social sustainability embedded in the practice of engineering? (3) What opportunities and barriers exist regarding global responsibility in engineering practice? EWB-UK had proposed the idea for this exploratory study to the UK’s Royal Academy of Engineering (RAEng) which agreed to support the project financially. Having the skills to conduct valid and reliable empirical research, researchers at the Centre for Engineering Education at University College London (UCL) were enlisted to produce the study, and a focus on civil engineering was mutually agreed upon for exploratory work.

Short-, medium-, and long-term objectives were identified. Short-term objectives are to: (1) identify and understand definitions and goals developed by leading organizations in the realm of global responsibility and engineering; (2) generate understanding of civil engineers’ day-to-day experiences, identifying how they learn and integrate knowledge of global responsibility; (3) produce findings that help benchmark how far the civil engineering profession has travelled and how far it might have left to go to achieve stated goals; and (4) identify implications for research, engineering practice, and engineering education. A medium-term objective is to help increase the rate of change and enhance overall success in civil engineering projects. A long-term objective is to help increase global sustainability across multiple sub-fields of engineering.

At its core, however, this study focuses on the interviewees’ experiences and their understandings of global responsibility. EWB-UK, the RAEng, the UK’s Institute for Civil Engineering (ICE), and the American Society of Civil Engineers (ASCE) have all contributed literature to assist in understanding the topic, but in this study, the research team does not define the term for interview participants. Participants are first asked about a time they made decisions in the realm of global responsibility, and near the end of the interview they are asked to summarize their personal definition of global responsibility. This sequence is intended to help the research team identify what topics resonate with participants—which concerns stick in these engineers’ minds—and ultimately influence their work and the buildings and infrastructures they produce.

Today, an exploratory study is well underway. It began with collecting data via personal interviews with nine individuals who work in civil engineering and allied fields. Although the size is small and cannot answer all questions EWB-UK and the RAEng have, the size is appropriate for exploratory study and consistent with many other studies involving analysis of in-depth interviews. Participants have been recruited via Tweets and email blasts from Engineers Without Borders UK, based on criteria agreed with the research team to yield maximum variation in responses. At this exploratory stage of research, which may be expanded later based on findings that emerge, grounded theory is the primary research methodology being used. Grounded theory is an optimal methodology for use in exploratory work (Savin-Baden & Major, 2013). Applying a lens of environmental sustainability further focuses the study, via a theoretical framework involving: (1) the UN’s Sustainable Development Goals (SDGs); (2) the concept of the three-legged stool seeking to balance concerns of environmental, social, and economic sustainability (see McDonough & Braungart, 2010), and (3) Raworth’s (2017) doughnut model depicting social and planetary boundaries. Interview data are being collected such that they will be appropriate for phenomenographic analysis in subsequent stages of the project, following initial analysis and interpretation, and collection of additional interviews. The primary value of this conference paper, however, is to researchers interested in designing similar studies and/or in discussing global responsibility at the Research on Engineering Education Symposium (REES).
Context

This work builds upon a solid understanding of social and environmental principles underlying and extending the Brundtland Report (Hauff, 2007) including Cradle to Cradle (McDonough & Braungart, 2010) approaches to Worldchanging (Steffen, 2008), and ways of encouraging, facilitating, and assessing progress (British Standard Institute, 2013; Chance, 2010, 2012). It also draws from emerging economic (Kelly, 2012; Rifkin, 2011; Rockström et al, 2009; Steffen et al, 2015) and regenerative models (e.g., Iverson & Chance, 2007).

The Royal Academy of Engineering has been supporting the development and distribution of educational tools and techniques to promote understanding of ethical issues among graduate engineers (Bourn & Neal, 2008). As a result, more and more young professionals are entering the practice of engineering with awareness of global responsibility and heightened understanding of the role engineers can play. The RAEng emphasises the urgent need for engineers to provide leadership in addressing environmental and social issues in the day-to-day aspects of their work. A hope is that the incoming generation of engineers can advocate for and enact change, infusing new knowledge into the profession. Although many graduate engineers have learned about ethics and are now under pressure to enact these values, they may not, however, have the professional standing and/or mastery of techniques needed to actually implement change.

The RAEng has interest in tracking results, and the organization provided seed funding to support exploratory work. An outline proposal was made by EWB-UK, and the organization later enlisted a team of experienced researchers to conduct the work. Together, the lead researcher and a team of expert advisors appointed by EWB-UK brainstormed relevant issues and framed the study; this steering group considered what problems engineers encounter when putting ‘global responsibility’ into practice, and how engineers balance their duty to ‘avoid harm’ on the one hand, with the duty to ‘do good’ on the other? More specifically, the steering group wondered, how do practicing engineers deal with commercial pressure and ‘value engineering’ when such pressures appear to be at odds with concerns for environmental or social justice?

A literature review is being conducted to provide background context. To date, literature has been reviewed and an annotated bibliography has been created. Those data will be synthesized soon, as results are derived from the empirical interview data and findings are distilled. In essence, the literature review is identifying the ‘who, what, when, where, why and how’ aspects of global responsibility and applying several different philosophical lenses to explore deeper underlying issues such as ethics, professional obligations and duties, and economic and political constraints. Aims of the literature review have been to distill shared understandings of ‘global responsibility’ that exist in engineering today, identify how leading organizations intend to achieve it, and explore philosophies underpinning the overall concept. A short overview is provided below to introduce REES readers to the topic.

“The sustainable development concept requires of all of us—as engineers and citizens—to consider much more widely than before the impact of our own lives and of the infrastructure and products we produce, both geographically and temporally” (Broers, 2005, p. 3). This is coupled with the belief that, “Through the application of science and engineering, humanity has the potential to meet all of its basic needs: water, sanitation, food security, shelter, energy, transport” (Bourn & Neal, 2008, p. 2).

The American Society of Civil Engineers (ASCE) led development of the vision statement that is most prominent across civil engineering world-wide. In June 2006, sixty thought leaders from around the globe—representing all career levels and having highly varied backgrounds—convened to define a global vision for civil engineering (ASCE, 2007). With this Vision for Civil Engineering in 2025, the members of this profession would lead global change as “master (1) planners, designers, and constructors; (2) stewards of the natural environment; (3) innovators and integrators of technology; (4) managers of risk; and (5) leaders in shaping public policy” (ASCE, 2009, p. 5). The statement offered “a bright,
ambitious goal [to] guide civil engineers around the globe [to] help achieve a sustainable world and raise the global quality of life [by embracing] a new level of leadership and responsibility for the global engine of societal betterment—the built environment” (ASCE, 2009, p. 9). It was noted that “Ultimately, only a few civil engineers may master all aspects of the Vision individually, but as a body of professionals, civil engineers should be viewed as mastering all that the Vision encompasses” (ASCE, 2009, p. 10). Although ASCE led the effort, this “was never intended as an ASCE or United States initiative” and the issues and goals identified are “not specific to any nation, culture, organization, sub-discipline, or practice area” (ASCE, 2009, p. 14).

After assessing who defines the term and the vision and strategy for achieving it, the literature review assessed what is meant by global responsibility across: (a) the engineering professions globally, (b) civil engineering, and (c) buildings. It looked at the past legacy of leadership in global construction across the profession of civil engineering, and the present situation, including current skills set of practitioners and the profession’s current focus on educating engineering students as agents of change. As Bourn and Neal (2008) explain, “engineering is a global industry. To be a global engineer requires not only understanding the global context but also recognising the contribution engineering can make to securing economic and social change” (p. 5). The effect of interconnected scales, systems, and decisions mean this is an inherently global topic.

Civil engineering has taken this global perspective seriously. In the UK, the Institute of Civil Engineers “was founded in 1818 […] the first engineering institution in the world” (Leiper, 2006, p. 3). And globally, “Civil engineers are rightfully proud of their legacy. During the past century, [via] clean water supplies […] Transportation systems […] bridges […] Towers […] the largely hidden water supply and sanitary sewer systems, civil engineers have made their mark in many aspects of the daily life of essentially everyone around the globe” (ASCE, 2007, p. 3).

The RAEng has provided workshops and tools for engineering educators across multiple sub-fields to develop mastery in teaching these subjects. The most prominent of these efforts is documented in Bourn and Neal (2008), whose publication “aims to provide UK engineering faculties and higher education institutions (HEIs) with practical guidance on incorporating global issues and sustainable development within the engineering curriculum” (p. 4). In the USA, the ASCE’s (2009) strategy provides a roadmap in that it “proposes 24 supporting outcomes and more than one hundred tactics. [and] more detailed action steps” (p. 14). According to ASCE (2009), realizing the vision means that:

> First, the global civil engineering community must broadly embrace the Roadmap […] Civil engineers around the globe must be informed, educated, and recruited to help achieve the Vision, and bring to the fore key issues for stakeholders. Finally, the whole effort must be monitored, evaluated, and measured over the long term, with course corrections made along the way. Such a broad activity set will not be centrally controlled […] In the end, the common, unifying driver will have to be the Vision, and the Roadmap to achieve the Vision. (p. 7).

The current study grows from Bourn and Neal’s (2008) recommendation for “Professional and research bodies to support further research on the impact and value of the ‘global engineer’ concept in the contribution of engineering to positive world change and meeting the skills needs of the UK workforce” (p. 3).

In conducting the literature review, the research team has been making effort to identify and assess underlying philosophies of ‘global responsibility’. They have looked at topics involving duty and morality (ranging from mandatory duties to actions that would be praiseworthy, but not required) and they considered duties to do good and the duty not to harm, as well as anti-corruption laws and practices. They questioned where responsibility lies (by considering
collective responsibility, how to impart values, and patterns and parameters of collectivising within the engineering profession in the UK). They considered obligations (special and professional), as well as economics (ranging from capitalism and free market ideology, to the place of engineering and technology within our economy), and the role of politics in the professions.

Research output
At the end of the exploratory phase of this study, the university-based research team will provide a research paper. Using this, EWB-UK will produce a formal report to help educators as well as students and the employers receiving them. Overall, this study aims to address intentions stated by the RAEng to promote focus on environmental, economic, and social sustainability in engineering practice as well as education. This is part of the Academy’s larger objective to increase the uptake of globally responsible decision-making, particularly with regard to environmental sustainability and social justice. This research is important to engineering education because educators aim to prepare students to identify, address, and solve global challenges. Understanding what graduate engineers have learned in university and then in practice, and how they experience decision-making in this realm are important.

Research questions
Data collected to date indicate the research team will be able to determine:

- In what ways do civil engineers in the UK understand ‘global responsibility’?
- In what ways do they experience decision-making with regard to global responsibility?
- To what degree are environmental, economic, and social sustainability valued and enacted in engineering built environments?
- With regard to global responsibility in engineering practice, what opportunities and barriers do participants describe?

Theoretical frameworks
As noted above, the theoretical framework for this study incorporates the globally-recognized SDGs along with the ‘three-legged stool’ (McDonough & Braungart, 2010) and Raworth’s (2017) doughnut model of social and planetary boundaries. This study seeks to understand if and how civil engineers balance competing concerns in their work today. At the most simple level, an appropriate balance can be visualized as the three-legged stool, with legs representing concerns that are: (1) economic, (2) environmental, and (3) social (McDonough & Braungart, 2010). At a more advanced level of conceptualization, Raworth’s (2017) doughnut model may also apply (see Figure 1) because many of the terms included in her model are applicable within civil engineering. Civil engineering relates to current shortfalls in housing, networks, energy, and water at the most obvious level, but can also be linked to shortfalls in food, health, education, income and work, peace and justice, political voice, social equity, and gender equality. Decisions civil engineers make have direct implications for current overshoot of the ecological ceiling in all areas on Raworth’s model: freshwater withdrawals, land conservation, biodiversity loss, air pollution, ozone layer depletion, climate change, ocean acidification, chemical pollution, and nitrogen and phosphorous loading. The key to providing ‘safe and just space’ for humans lies, according to Raworth’s model, in creating a regenerative and distributive economy. Thus, the research team also will be able to identify:

- Which aspects of Raworth’s model have been articulated by civil engineers in the sample group?
EWB-UK has embraced the UN’s Sustainable Development Goals as core principles guiding its efforts (see Figure 2) and the team will also consider which of the SDGs figure prominently in interview narratives.
Methodology

In the exploratory phase, the research team is using grounded theory methodologies. This involves the type of thematic analysis (e.g., involving open, axial, and selective coding) defined by Strauss and Corbin (1994). NVivo 12 is being used for data management and the project was approved by UCL’s ethics review board. By using grounded theory, the research team aims to: (a) identify patterns; (b) describe implications of these patterns; and (c) generate recommendations for engineering education, research, and practice. This is a topic of great interest to the Royal Academy of Engineers—they want to hear the voices of practitioners and understand what barriers keep engineers from realizing their full potential to positively affect social justice, climate change, and the like. As such, grounded theory is an ideal method and will be used at stage one.

To ascertain differences in the way individuals experience and conceptualize things—such as global responsibility, environmental sustainability, social sustainability, and personal and professional responsibility—individual interviews are often collected. Discussions with individuals are seen as more effective than those conducted in focus groups when diversity of opinion and/or perspective is sought. Bruce (1994) explains that in situations where there are multiple interviewees, participants tend “to move towards positions of agreement rather than diversity” (p. 53) and differences in their ideas are more difficult to identify. To address the stated research questions, the researchers have aimed to collect data via personal interviews with nine individuals who work in civil engineering and allied fields.

To date, all but one participant has been within ten years post-graduation; the sample group reflects a wide variety of job focus (design, site operations, cost estimating, theoretical and applied research, and management). The data collected are appropriate for analysis using phenomenography as well as grounded theory. Collection of additional data in the future may facilitate more specific analyses (phenomenography requires a minimum of 20 participants and far more time than available under the current funding model). In future sampling, the team will aim for even greater diversity of interviewees, with regard to their project roles (i.e., client, graduate engineer, directing role, or management role) as well as focus (i.e., stages of Design, Construction, Commissioning and Operations, and Demolition or Renovation).

However, for an exploratory study, grounded theory is appropriate and will help the team define appropriate questions, theoretical frameworks, and methodologies for additional work.

Consistent with established methods of both grounded theory and phenomenography (Åkerlind, 2012; Ashworth & Lucas, 2000; Bruce, 1994; Marton, 1986), the first and second author on this paper conducted semi-structured, phenomenographic interviews that were conversational in nature. Interviewees touched on topics such as carbon footprint, material consumption, transportation and logistical efficiency, emergence of new technologies, social equity, familiarity with the UN’s Sustainable Development Goals, and pro-bono/outreach/volunteer work.

Interviewers prompted participants to identify and describe their own concepts of ‘global responsibility’ rather than presenting any a priori description of ‘global responsibility’. Questions focused on participating engineers’ experience of dealing with issues of global responsibility, asking participants to provide details about specific occurrences rather than general/abstract impressions or conceptual ideas. This was intended to shed light on problems that engineers have faced in trying to implement their ideals in practice, and what they have found to be stopping them.

Interview questions

The following interview schedule guided the collection of empirical data.

1. Please tell me about an instance in your recent work as a civil engineer where you made decisions related to ‘global responsibility’. Probe any of the following, as appropriate:

   • WHAT happened?
• WHAT was the context of the experience?
• WHO was involved?
• WHEN did this happen?
• WHERE did this happen?
• WHAT influenced your decisions?
• WHY did that topic matter to you?
• WHAT was the outcome?
• HOW did you see ‘global responsibility’ relating to that situation?

2. HOW did you learn about global responsibility?
• WHAT stage are you at in your career?

3. WHAT attracted you into civil engineering?

4. With regard to global responsibility:
   • WHAT barriers have you faced? Anything particularly stressful or corrupt?
   • WHAT opportunities do you see?

5. You mentioned earlier that you… [faced a specific challenge]. What prior experiences helped prepare you to meet this challenge? Probe any of the following, as appropriate:
   • HOW did you learn about that [topic you mentioned]?
   • HOW did that affect your decisions?
   • HOW did you resolve that?

6. At this point, can you please SUMMARIZE how you define ‘global responsibility’?

7. Do you have any other examples of times you considered ‘global responsibility’ in your work?

8. Before we conclude, is there anything you would like to add that you haven’t had a chance to talk about. Probe: Is there anything else you’d like to say, for example, about…

Conclusions

To date, the team has collected a wide range of descriptions from participants regarding their experiences and ideas of global responsibility. The data are indeed appropriate for both grounded theory and phenomenographic analysis. However, there are limitations to the current dataset due to small size and the fact that participants were recruited via email blasts originating from EWB-UK. While not all participants are EWB-UK members, the sample is somewhat skewed. People near the UCL campus and comfortable enough to discuss an ill-defined topic (advertised as ‘global responsibility’) signed up to participate. If the study is expanded, we may work to recruit a more diverse group with people not connected to EWB-UK. By the time of presentation in Cape Town, the team will have identified themes and be able to share findings via an A4 handout including implications for engineering education. Based on themes emerging from initial coding, we believe that the conceptual framework provided by Meadows et al (1972) (see Figure 3) may be valuable as a lens for interpreting results.
This way of analysing the world can complement the Raworth (2017) framework and any analyses conducted to identify overlaps between narratives and the United Nations (2015) SDGs. In combination, these three frameworks can serve as lenses for reading data through and the process can generate new understanding of the narratives provided by interviewees.

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The development of engineering identity in an electrical engineering degree programme

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Abstract: Developing students’ engineering identity during higher education is a way to encourage perseverance as well as identification with the engineering role after graduation. This study explores the constraints and enablements to the development of engineering identities experienced by a group of final-year electrical engineering students during their studies. Drawing on data generated from focus group and individual interviews, the study utilises Margaret Archer’s social realist concept of triple morphogenesis as an analytical framework. The findings show that engineering identity development was enabled by the aspects of the programme that encouraged personal development and by exposure to a range of different engineering-related careers. Constraints included conventional top-down pedagogy and assessment and a lack of focus on the creation of authentic texts. The recommendation is for engineering programmes to prioritise holistic growth and explicitly focus on engineering identity in their curricula.

Introduction

Scholarship in the field of engineering education has shown that there are many benefits to developing understandings of how engineering students develop their professional identities (Paretti & McNair, 2012; Stappenbelt, 2013; Tonso, 2006, 2014). One functionalist benefit stems from the understanding of engineering identity (or lack thereof) as a mediator for other important educational issues. For example, Tonso (2014) shows that the strength of students’ identification with engineering can be critical in terms of their persistence, with those who experience a lack thereof often migrating to other fields of study. Similarly, graduates who leave higher education strongly identifying as engineers may be more likely to remain in the industry once they enter the workplace (Eliot & Turns, 2011). There is a shortfall in the numbers of engineers in South Africa, where one engineer services 3166 people, compared to Brazil's 227 and Malaysia's 543 per engineer (ECSA, n.d.). Thus, research that could potentially lead to a higher number of graduates desiring to remain in the engineering profession could ultimately be for the public good, as engineers are vital for infrastructure development and subsequent economic growth.

A more conceptual benefit of research into engineering identity emerges from the widened understanding of professional development in higher education away from the attainment of a set of isolated, decontextualised skills to a process whereby students undergo changes in identity. This represents a move away from what Bridges (1993) refers to as the “transfer metaphor”, in which students are understood to pick up professional skills such as report writing or presentation skills during higher education and transfer these neatly and wholly into the workplace. This conceptualisation of professional development is limited because it presents an overly simplistic notion of learning, which should more accurately be viewed as an ongoing, complex set of processes rather than as a series of discrete acquisition events (Hager & Hodkinson, 2009). Moreover, Fenwick (2013) highlights that the transfer metaphor is problematic because it assumes that spaces and places (for example, higher education...
institutions and workplaces) remain static and stable while an individual moves between them. It thus ignores the "continuous dynamics through which space is open, relational and multiple, socially produced and productive of social relations" (Fenwick, 2013, p. 361), flattening out the journeys that individuals actually trace as they transition from, between and to new contexts.

This study counters this one-dimensional understanding of professional development by focusing on the identity work of a group of final-year electrical engineering students. In doing so, it draws on Hager and Hodkinson's (2009) metaphor of learning as transformation and Holmes's (2013, p. 549) notion of professional development during, through and after higher education as an "identity project". This implies that during higher education, engineering students should not just be learning decontextualised skills that engineers may or may not utilise in their working lives. Instead, the challenge for engineering educators is to find ways to enable processes whereby students actually become engineers. Dall'Alba and Barnacle (2007) call for a turn away from a sole focus on epistemological concerns within higher education to the ontological implications of learning. According to this perspective, knowledge is not restricted to the realm of thoughts, ideas, and concepts; rather, it is understood as embodied and enacted by the individual. Learning thus becomes the "development of embodied ways of knowing or, in other words, ways-of-being" (Dall'Alba & Barnacle, 2007, p.683). No longer is it sufficient for students studying a particular profession to master new skills or concepts; instead, they need to transform as individuals to become architects, teachers, doctors or, in this study, engineers. This paper describes factors that both encouraged and stifled this transformation for a group of final year electrical engineering students during the degree programme.

Context

The electrical engineering students who formed the sample group for this study were nearing the completion of the four-year BSc(Eng) degree from the University of Cape Town (UCT). This degree programme is one of the professional engineering qualifications accredited by the Engineering Council of South Africa (ECSA), the statutory body established in terms of the Engineering Profession Act 46 of 2000 to regulate the profession in the country. (In addition to the BSc degree programme, ECSA also accredits the more practically orientated National Diploma and the BTech degree.) With regards to the BSc degree programmes, ECSA provides guidelines for structure and content. The degree programmes must consist of a minimum of 560 credits and must have a coherent core comprised of mathematics, natural sciences and engineering fundamentals. Moreover, 56 credits must be allocated to the knowledge area that ECSA terms "complementary studies" (ECSA, 2014a, p. 9). This, according to ECSA, refers to fields which are...disciplines outside of engineering sciences, natural sciences and mathematics which are relevant to the practice of engineering including but not limited to engineering economics, management, the impact of technology on society, effective communication, and the humanities, social sciences or other areas. (ECSA, 2014a, p. 9)

In addition to these guidelines, ECSA also stipulates 11 exit-level outcomes (ELOs) that students must be able to demonstrate in order to graduate (ECSA, 2014b). These include: problem-solving; application of scientific and engineering knowledge; engineering design; professional and technical communication; and individual, team and multidisciplinary working. While ECSA stipulates these outcomes, it is up to engineering departments to determine how students achieve them, and, as such, ECSA does not specify elements such as curriculum content, teaching methods or assessment tasks.

Students undertaking a BSc in Electrical Engineering at UCT enrol in one of three programmes: electrical engineering, mechatronics engineering or electrical and computer engineering. The differences between these programmes are shown in Table 1 below:
Table 1: Undergraduate programmes offered by the UCT Department of Electrical Engineering

<table>
<thead>
<tr>
<th>Programme</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrical Engineering</td>
<td>A comprehensive grounding in electrical engineering with the option to specialise in heavy current (including power generation, alternate energy, transmission and machines) or light current (including electronics and analogue circuitry).</td>
</tr>
<tr>
<td>Mechatronics Engineering</td>
<td>Theory and practices relating to the development of mechatronic systems (systems that combine mechanical engineering with light-current electrical engineering) including instrumentation and control.</td>
</tr>
<tr>
<td>Electrical and Computer engineering</td>
<td>Theory and practices relating to the development of mechatronic systems (systems that combine mechanical engineering with light-current electrical engineering) including instrumentation and control.</td>
</tr>
</tbody>
</table>

Certain courses offered in the Department of Electrical Engineering are taken by students enrolled in all three of these programmes. These include Engineering Mathematics, Engineering Statistics and Engineering Physics. However, each programme also contains more specialised courses. Furthermore, while the first three years of the degree programme are quite general, covering fundamentals of the electrical engineering disciplines, final year courses offer some degree of specialisation (EBE, 2019). Also, students complete a research project on a topic of their choice.

It is evident from the above that by the time they reached final-year, students enrolled in an electrical engineering degree at UCT would have been exposed to a programme focussing predominantly on developing engineering-related knowledge. Also, they would have had exposure to some “complementary studies” courses, which in the UCT curriculum included the following compulsory courses: Professional Communication Skills; Culture, Identity and Globalisation in Africa; and Industrial Law. Furthermore, the entire curriculum would have been underpinned by the ECSA ELOs, ensuring that opportunities were provided for the students to practice “soft” skills such as teamwork, communication skills, and leadership skills. How this learning experience enabled or constrained the development of engineering identity in the research sample is the focus of the rest of this study.

Research question
What constrained and enabled the development of engineering identities for a group of final-year electrical engineering students?

Theoretical framework
As discussed above, this study draws on the conceptualisation of engineering education as the process through which students develop engineering identities. To develop understandings around how this transformation can occur, this study draws on Margaret Archer’s social realism (SR). This analytical tool provides a framework for how structural and cultural powers impinge on people and how people use their own personal powers (agency) to act in particular ways in specific situations (Archer, 1995). It does so through the methodology of analytical dualism (Archer, 1995), which is based on the premise that
structure, culture, and agency are temporally distinguishable. According to this understanding, while structure, culture, and agency always overlap, intertwine and influence one another, it is possible to analytically separate them for research purposes. This offers a means of examining them independently to understand the ways in which they either elaborate/change or preserve/maintain the status quo (Archer, 1995). Archer terms the former scenario “morphogenesis” and the latter “morphostasis”. It is in this analytical separation that the appropriateness of SR for this study becomes evident. Through analytical dualism, SR provides the researcher with a tool to focus on how a person changes over time. It is thus a productive way to understand how shifts in identity may or may not occur.

As a means to operationalise analytical dualism, Archer advances the morphogenetic cycle. Figure 1 below depicts the stages of the morphogenetic cycle. ("T" represents a given time.)

```
<table>
<thead>
<tr>
<th>T1</th>
<th>T2</th>
<th>T3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Structural Conditioning</td>
<td>Socio-cultural interaction</td>
<td>Structural elaboration (morphogenesis)</td>
</tr>
<tr>
<td>Structural reproduction (morphogenesis)</td>
<td>T4</td>
<td></td>
</tr>
</tbody>
</table>
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Figure 1: The basic morphogenetic/static cycle (Archer, 1995, p. 157)

Structure, culture and agency each have their own morphogenetic cycles, which are continuously operative in society. Given that this study aims to generate knowledge around the development of students’ engineering identities, its focus is on the morphogenesis of agency. T1, according to Archer (1996, p. 90), is the context of structural, cultural or socio-cultural conditioning, which is considered to be the emergent consequences of previous actions (Archer, 1995, p.90). In this study, this would be the point at which the students began their electrical engineering studies. T2-T3 is the social, socio-cultural and group interaction, which is structurally conditioned but not structurally determined since human agents will ultimately decide how/when to act in a particular situation. In this study, this relates to the years that the students spend in the degree programme. T4 represents the state of the system at the end of a period of social or socio-cultural interaction, which in this study is the point, nearing the end of the programme, at which the data was gathered.

Within the broad framework of agential morphogenesis, this study focuses particularly on what Archer (1995, p. 255) terms “triple morphogenesis”. This is the process whereby agents become social actors by finding roles in which they feel they can invest themselves. Archer (2000, p. 296) calls an individual who has managed to attain both a social and personal identity a “successful subject”. In the context of this research, this “successful subject” would be a student who graduates from the electrical engineering degree programme at T4 as a social actor, embodying the role of “engineer” in balance with his/her personal identity. The purpose of this research was to determine the constraints and enablements that contributed to the development of the students as social actors or, in other words, to their engineering identities.
Methodology

The methodology for this study consisted of two stages: focus group interviews and individual interviews. The focus group interviews were held with 20 final-year electrical engineering students. The decision to conduct focus groups at the initial stage of this research was supported by Kelly's (2006, p. 306) notion of focus group interviews as a means to promote access to “intersubjective experience”, which is an experience that is shared by a community of people – in this case, the experience of studying electrical engineering. Focus group interviews are synergistic (Finch & Lewis, 2003), and the students’ interactions with one another contributed to deepened descriptions of their experiences of being engineers-in-training. The sampling methods used to identify participants in these interviews were both purposive and convenience sampling. With regards to the former, the demographics of the students were diverse in terms of age, social background, race, country of origin and gender. This was done to obtain access to a full range of perspectives and experiences. With regards to the latter, the students were all enrolled in a course run by the author’s department and were thus easily accessible. The focus group questions dealt with the students’ general perceptions of aspects of the electrical engineering degree, for example the skills and knowledge that are the focus of the programme, students’ concerns for the future and motivating factors. Six focus group interviews were held, with the number of participants in each varying from three to four, depending on student availability and willingness to participate. The focus group interviews were recorded and then transcribed.

In the second stage of the research process, individual interviews were held with 11 of the students who had participated in the focus group interviews. Students who had stood out in the focus group interviews as having the potential to make a unique contribution to the research regarding engineering identity development were approached to participate. For example, Mike was already running his own engineering-related business, meaning he straddled two identities concurrently: student and engineer. Although Faith, who had consistently achieved high marks throughout the programme, was nearing the end of her studies, she was quite sure she did not want to work as an engineer once she graduated. This purposive sampling provided a wide pool of experiences for analysis. While it is clear that the study’s sample was by no means extensive, it is in line with qualitative research which typically studies a small number of individuals or situations so that the individuality of each of these can be preserved in the analysis (Maxwell, 2013). In this way, a deeper understanding of how events, actions and meanings are shaped by the circumstances in which they occur is possible. For the individual interviews, the questions were more specific to each interviewee. Students were asked to reflect on particular moments of their degree programmes, the skills and knowledge they did or did not develop and any shifts that occurred in terms of their understandings of their identities as professional engineers.

With Archer’s morphogenesis of agency as analytical framework, the interviews were transcribed and then analysed using the Nvivo computer-assisted qualitative data analysis software (CAQDAS). The affordance offered by CAQDAS is that it provides researchers with a means of storing, retrieving, coding and sorting data (Nudelman, 2017). The process of coding was informed by the distinction that Maxwell (2012) draws between organisational, theoretical and substantive categories. Organisational categories are broad areas and issues that may be identified before the generation of data and can be understood as "bins" for sorting the data for further analysis. In this study, this included broad categories such as "electrical engineering degree in general", "non-engineering courses" and "career goals". The theoretical categories related to the morphogenetic cycle. Thus, the data were organised according to whether they related to T1, T2-T3 or T4 of the morphogenetic cycle, personal and social identity. Finally, the substantive categories, which according to Maxwell (2013) are primarily descriptive and include descriptions of participants' concepts and beliefs, were coded for. Some of these included "connection to engineering profession", "learning styles" and "feelings about grades".
Findings and conclusions

According to this study’s theoretical framework, the students in this study could be said to have developed engineering identities at T4 of the morphogenetic cycle of agency, where they emerged as social actors. This represented the moment of synthesis between their personal and social identities, whereby the students found that the role of “engineer” was one that they were willing and able to commit to and enact. According to the data collected, there were two main ways in which this occurred for the students.

First, students were more likely to become social actors when their academic activities contributed to their personal development. One example was offered by Angela, who highlighted the positive impact of having reflection opportunities built into the coursework. Faith spoke about how her leadership skills had developed through the process of small-group work. Paul shared the experience of having to become resilient in the face of poor grades over the years. In all these cases, what the students gained were not the skills and attributes that are common amongst those who understand professional development as the possession of generic, clearly-defined workplace requirements, such as report writing or presentation skills. Nor were these areas of personal growth explicitly taught or assessed. Instead, they can be understood as by-products of the formal curriculum. It was in the “messiness” of fulfilling the academic requirements of the electrical engineering programme, such as meeting deadlines or working with others, that the students encountered these moments of personal learning. This enabled their agential transformation because the strengthening of personal identity meant that the students would be better equipped for and more confident in their choices regarding their adoption of the engineering role and the way(s) in which they planned to personify it.

The second enablement for the students’ development of engineering identity was through those elements that helped to deepen their understanding of what the role of engineer entailed. This presented them with the means through which to “pick and choose” the aspects of the role that appealed to them and thereby negotiate the shape of their own identities as engineers. For example, Vuyo described how exposure to guest lecturers during the degree programmes had made him aware of the wide range of career possibilities for an engineer, and how this had excited him. For Ravi, working on different types of texts, such as a poster and presentation during a course on professional communication, changed his perception of the engineering role from a purely technical pursuit to one that required creativity and a capacity to connect with people from different disciplines. From a business-oriented course, Paul came to realise that a focus on finances was an essential aspect of the engineering role. In all of these cases (which fall under the area that ECSA terms “complementary studies”), the students’ knowledge of what being an engineer entailed was deepened; this meant that it enabled their agential morphogenesis in that, when in T4 they made the choice to commit to the engineering role, they had a fuller picture of what this actually involved.

Contrastingly, there were also aspects of the programme that constrained the students’ morphogenesis. For example, the typical pedagogy of most engineering courses, which consisted of lectures being delivered to students on a variety of topics by different lecturers without any clear overview or explication of how these linked up, meant that students struggled to grasp the relevance of the content. Also, several students described how most of their tests and exams required them to memorise material verbatim. For example, Mike explained that while he could do the required derivations for his Networks course, he had simply “memorised all the X’s” – he still had no real understanding of what he was doing. This “surface” approach to learning (Ramsden, 2003) meant that students did not need to work with the material in a manner that would have built connections between the course content and what they already knew from their general knowledge or previous university courses.
Another way in which both personal and social identity development on the part of the students was constrained was a lack of emphasis on the creation of authentic texts, which Lombardi (2007) describes as creating genuine interpersonal, intellectual and personal connections for the reader. For example, while the business oriented course mentioned above did require that students create a business plan and funding pitch, these both focussed on a hypothetical new venture product. While these texts were simulacrums of what actual engineers may create in industry, they could not be said to be authentic texts. Angela explained that she was aware throughout the development of her business plan that there were no real industry-related implications to misrepresenting the product or finances, since it was merely an academic project, and this had limited her personal engagement with the task. Yasin was sure that the negative mark given to his group on their business plan was in contrast to the positive response they would actually receive in industry. Had the task required students to develop a solution for a real personal, social or environmental issue, they would have engaged more authentically with it, thereby either undergoing personal growth or developing a better sense of the social good aspect of being an engineer. This, in turn, could have encouraged more students to become social actors.

Recommendations

The recommendations emanating from this study take place on two levels: pedagogy and future research. With regards to pedagogy, the study’s findings indicate that the development of students’ engineering identity should be a priority for tertiary engineering programmes. This implies that engineering programmes should not only focus on technical material to the detriment of encouraging holistic growth in the students. Given that the aspects that constrain agential morphogenesis (i.e. top-down pedagogy, rote learning and lack of emphasis on authentic tasks) could be as prevalent in “complementary” courses as in straight engineering courses, this recommendation does not focus on what is being taught, but rather on how teaching and learning occurs. Engineering education programmes would benefit from a more explicit focus on promoting student agency in the formulation of curriculum, assessment methods, and pedagogic strategies. This is because, while some of the students did become social actors by the end of their studies, thereby demonstrating acceptance and embodiment of the engineering role, when this occurred, it was largely a by-product of the formal curriculum.

Including the development of students’ engineering identities as a core objective of engineering programmes could result in students being encouraged to find ways of actively balancing their personal and social identities throughout their studies. This would mean that ongoing identity work would be integrated into engineering programmes, making it a fundamental part of the students’ experience, as opposed to a superficial add-on that is perceived as being less important than the technical engineering material. There are various ways that this could be integrated into engineering programmes. Some of these include: mentorship programmes; peer support groups; ongoing reflective processes, which could include, but are not limited, to writing activities; and a higher degree of interaction with industry through site visits and guest lecturers.

The study opens up many possibilities with regards to further research. First, while this study has developed understandings concerning how the students developed identities as engineers during their studies, it could be valuable to conduct follow-up research on the same cohort of participants, who would likely have graduated and entered the workforce by the time of writing. The purpose of such research would be to understand how the findings concerning whether or not they developed identities as social actors correspond to the paths that they have followed in their lives and careers after graduation. Second, while this study dealt with workplace readiness for students enrolled for a BSc degree at a traditional university, similar studies could be carried out with students studying towards national diplomas and BTech degrees at other higher education institutions in South Africa. As engineering technicians and technologists, such graduates will also play an essential part in
the engineering industry, and, as such, it is also vital to understand how they are prepared to make the transition from their HEIs to the workplace.

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Understanding female students’ dissatisfaction in first-year engineering teams

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Abstract: One common strategy in engineering student team formation is to avoid isolating underrepresented students, like women, on teams. However, it has been found that women who were isolated on engineering project teams were significantly more satisfied with their team than women who were not. In this work-in-progress paper, we investigate the experiences of women in teams to determine what contributes to dissatisfaction in teams. We conducted 14 interviews with female students, and then used thematic analysis to create a codebook that describes female students’ experiences and dissatisfaction in teams. Here, we present our final codebook, containing themes categorized as Treatments that women experience in teams, Feelings that women have due to how they have been treated, and resultant Behaviours that female students exhibit. The themes found in this study elucidate several aspects of team experiences that can lead to female students’ dissatisfaction, and illuminate implications for engineering educators working with student teams.

Context
Project-based learning is important in engineering education to give students a chance to work in teams to actively apply their skills and knowledge to authentic engineering scenarios (Dym, Agogino, & Eris, 2005; Prince & Felder, 2006). However, the project experience may not be beneficial for students if their team experience is not positive.

For female students, specifically, there are many potential difficulties that can be encountered in project teams. Because engineering is a traditionally male-coded, and still male-dominated, discipline, the culture tends to cater towards male interests, stereotypical male personalities, and thus, away from better supporting women or students in underrepresented groups (Hill, Corbett, & St Rose, 2010; Tonso, 1996). Similarly, engineering work is often considered to be stereotypically male (Eagly & Karau, 1991), and this is one of many reasons why women may participate less equitably in project work.

Another reason that a woman may have a negative team experience or, more specifically, a reason why she may not engage fully in project teams, is that there are enduring stereotypes that women are not as proficient at engineering. Women who are aware of these stereotypes may have lower motivation to engage in teamwork or project tasks (Bell, Spencer, Iserman, & Logel, 2003; Quinn & Spencer, 2001) and can also lead women to have less confidence in the engineering field (Marra & Bogue, 2006; Seymour & Hewitt, 2000). These same stereotypes may also lead to other team members (male or female) perceiving female team members as less capable, and thus assigning them a lower status (Horn, 2012). This perceived lower status can lead other team members to treat women as “less than” or assign or delegate less technically-challenging tasks to their female team members due to lack of trust or belief that they would not complete the tasks successfully. Similarly, women (or other underrepresented students) may not feel that they are “allowed” to do more technical work on teams, for a variety of reasons, and thus may self-select into certain roles that are less challenging or satisfying. Accordingly, studies have shown that male students are more likely...
to take on or present technical work, while women are often relegated to traditionally female tasks like organizing, notetaking, or writing (Hirshfield, 2018; Linder, Somerville, Eris, & Tatar, 2010; Meadows & Sekaquaptewa, 2013).

To attempt to avoid these difficulties that students can experience in project teams, there are several “best practices” for forming student teams for course projects (Oakley, Felder, Brent, & Elhajj, 2004). One recommended practice is to avoid isolating women (or other underrepresented students) on teams (Rosser, 1998; Tonso, 2006). By grouping women on teams, the hope is that women feel more empowered to have a voice and not take on or be assigned more passive roles within the team (Heller & Hollabaugh, 1992).

However, it is important to consider whether this pedagogical strategy has the intended effect. A recent quantitative study of 620 first-year engineering students working in 132 teams found that both male and female students on teams with two or more female members were statistically significantly less satisfied with their team experiences than all-male teams or teams with one woman (Fowler, 2016). Although team satisfaction is by no means a suitable metric for all aspects of team dynamics (particularly project performance or growth), it is one way to gauge how students perceive their team generally. And, according to these findings, teams who had more than one woman were perceiving their teams more negatively.

Following this quantitative study, mixed-gender focus groups were conducted to discuss the finding. In these focus groups, female students were surprised by this result (Bartholomew, 2016). Although the focus groups illuminated some perceptions that students have about the impact of gender makeup on team satisfaction, it also revealed that there was a clear need to better investigate exactly what is happening on teams to determine what is leading to a lower satisfaction in teams that should theoretically be better for female students.

Thus, a more in-depth qualitative study was conducted to delve deeper into understanding what is happening with female students on engineering project teams, in order to better understand what may be leading to a dissatisfying team experience. In this work-in-progress paper, we present the initial findings of our investigation, exploring female students’ experiences in mixed-gender teams in order to determine what may be leading to a dissatisfying experience.

**Research Questions**

The primary impetus for this study was the finding that teams with two or more women are significantly less satisfied than teams with one woman. It is undeniable that women can be dissatisfied in teams for a multitude of reasons; however, it was surprising that women are more dissatisfied when on a team with another woman, when a common practice is to ensure that women are paired together. Therefore, our main research questions driving this work included:

1. How do teaming experiences of female students differ between teams where they are isolated compared to teams where they have one or more other female team member(s)?
2. What contributes to female students’ dissatisfaction on teams, both when they are paired with one or more other female team member and when they are not?
3. How does satisfaction (or dissatisfaction) on a team relate to the tasks that female students take on?

In this paper, we present preliminary findings that begin to provide a foundational understanding of female students’ experiences in team, which will ultimately allow us to move toward answering these research questions more fully.

**Methodology**

This study was a qualitative research study, focused on collecting and analysing female students’ perspectives on their experiences in first-year engineering team project courses.
Participants

This paper presents the findings from interviews with 14 female students. All of the female students were sophomores at the time of the interview (winter/spring semester of 2018). In this work, the students are all referred to with pseudonyms F1, F2, etc., through F14 (where F stands for female).

Setting

The participants were reflecting on their experience in a mandatory first-year engineering course in the 2016-2017 school year that incorporated a significant team project experience, located at a large public university in the Midwest region of the United States. The first-year engineering course consisted of both a technical communication (writing, presenting, etc.) component and a technical component, and sections of the course differed based on the technical component. The technical components were typically focused on introducing students to basic fundamentals of different engineering disciplines. A few examples of the technical course components include: a computer science-based focus on creating a computer game for children with disabilities; a biomedical engineering focus on researching and proposing an innovative medical device; an aerospace engineering focus where students operate and analyse findings from a weather balloon, etc. Students were also prompted to reflect on other team experiences they have had; thus, students were able to reflect both on team experiences in which they were paired or not paired with other women, although the primary focus of the conversation was on their experiences in the first-year engineering team.

Data Collection

Data was collected via a semi-structured interview protocol which involved three phases:

1. General questions about the team project: This first phase of the interview asked students open-ended questions about their experience in their first-year engineering project. They were asked to describe their course and course project, their team members, the tasks that they completed as part of the team, and things they wish they had differently in the team, such as if there were any tasks that they completed but did not want to or tasks that they did not complete but wish that they did.

2. Gendered experiences in the team project: After students described the project generally, they were asked more pointed questions about their experience as a woman in the project team. They were asked if they thought their experience in the course or tasks they completed in the team would be different if they were male. They were also asked to compare team experiences as a sole woman on a team versus being paired with one or more woman on a team, in order to discuss how gender makeup of the team impacts their experience.

3. Team satisfaction and how it relates to gender makeup of the team: In this phase of the interview, participants were shown the results of the team satisfaction study (in which teams with two or more women are statistically less satisfied than teams with one woman). Participants were first asked to speculate why this finding may occur. After the participants were done hypothesizing, they were asked about their agreement or disagreement with specific scenarios that were identified in the previous focus groups as potential reasons for dissatisfaction on teams (i.e. “maybe women are competitive with one another”). Therefore, students were first able to respond to completely open-ended questions, before being prompted by example scenarios as well; the analysis done in this work, however, was primarily on the open-ended portions of the interview.

Data Analysis

After the interviews were transcribed, they were analysed using thematic analysis (Braun & Clarke, 2006, 2012) to classify and generalize themes that arose across the dataset, without a specific theory guiding the work.
The research team that coded this work was comprised of two high school research interns who were enrolled in an engineering academic curriculum and two faculty members who conduct engineering education research (the two authors of this paper). The interns were first given an introduction into qualitative research and analysis before commencing the coding process. Although the interns were new to qualitative research, they were able to give valuable insight into what it is currently like being a female member in an engineering student team.

Initially, the four researchers coded the same three interviews, which were randomly selected. After coding, they discussed the themes that arose, and then they discussed combined and reworded their codes to assemble an initial codebook. Next, they coded the rest of the interviews using both the initial codebook and emergent coding (in order to capture any experiences not demonstrated in the first set of interviews). After this, the researchers all discussed new themes, any changes to be made to the existing codes, and merged codes that were similar.

By this point, three over-arching categories of themes emerged (Treatment, Feelings, Behaviour) as presented in the Findings section below. Once this final version of the codebook was created, the researchers each re-coded 4-5 interviews using the new codebook, ensuring that each interview was separately coded by at least two people. This final coding process led to the identification of the examples provided below (Tables 1-3). Interrater reliability has not yet been calculated for this codebook; the purpose of this work-in-progress paper is to present the initial codebook that will now serve as the foundation for future work.

**Findings**

In the final stage of iterating on the codebook, three categories of themes emerged: Treatment, Feelings, and Behaviour. When female students discussed their dissatisfying teaming experiences (regardless of gender makeup of the team), they presented elements of the team experience that could be categorized as either external factors, internal emotions, or ways that they acted on their teams. These three aspects of the team experience became the three categories of the codebook described below. It is important to note that the themes within each category relate to and, likely, influence the other categories: Treatment that female students experience influence their Feelings about the team or project experience, which influence female students’ Behaviour, which of course can then circle back to impact the ‘Treatments’ they then receive, etc.

Below, we present the codebook, along with definitions and analogous examples from the interview transcript.

**Treatment**

One set of code categories was Treatment. The themes in this category all have to do with how women perceived to be treated externally by others while working on her team project; it could be as general as describing societal norms that impacted her, or as narrow as discussing treatment from a specific member of her team or the course instructional team.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Definition</th>
<th>Example(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male-coded institutional culture</td>
<td>Overarching engineering culture that traditionally caters towards males</td>
<td>F3: There's always something off when you're a girl in engineering classes, just because that is currently the culture. I think it's just more noticeable.</td>
</tr>
<tr>
<td>Male-coded course structure</td>
<td>Course pedagogy or structure that is catered towards stereotypically male topics or qualities</td>
<td>F8: I have noticed that just in Computer Science and Engineering, most assignments are tailored to what one might consider stereotypical guys' interests. Like all coding projects are like, program a football game.</td>
</tr>
</tbody>
</table>
Ignorance
Others are oblivious to difficulties that women face in engineering disciplines
F8: I ended up doing a project around women in computer science and stuff. And I presented it to all these guys and they’re like, what? Like that’s crazy. I was reading them these statistics about women in engineering and stuff. And it’s definitely very isolating to have this weight of being the only girl in the class and having all these guys not even think about how I’m feeling.

Exclusion
Others prevent women from participating or engaging fully, either knowingly or unknowingly
F2: Our lab group, the boys just would always just take control of whatever technical applications we’re doing in the labs. They wouldn’t let us touch any of the equipment. We were not learning as much as we thought we could have.
F12: With working in other coding stuff... they’re like, "oh, I know what I’m doing so I’ll take care of it." I’m like, "I can do this better than you, but ...".

Patronization
Others make women feel inferior
F8: There were moments that the two guys kind of brushed us off, like they didn’t really give us an opportunity to do the coding, and then they would kind of like mansplain what they were doing.

Feelings
The second category of codes is Feelings. This category of themes refers to internal emotions or thoughts that women are feeling, typically as a response to Treatments that they endured.

Table 2. Themes pertaining to the Feelings category.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Definition</th>
<th>Example(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representing their gender</td>
<td>Feeling pressure to prove themselves or speak on behalf of all women</td>
<td>F3: You’re representing your gender. You want to work hard and do well so you can prove yourself.</td>
</tr>
<tr>
<td>Competitive with other women</td>
<td>Women feel that they need to establish superiority over the other woman/women on their team</td>
<td>F8: I think there’s also kind of a lot of girl on girl competition. It’s definitely very common for there to be girl on girl hate. I think it’s very common for girls to be together and just feel very competitive. We just inherently feel like we always need to prove ourselves. So, when we’re with another woman we do that with them as well.</td>
</tr>
<tr>
<td>Friendly with other women</td>
<td>Feeling a kinship specifically with other women on the team</td>
<td>F12: When you first walk into a classroom you kind of look for like, &quot;Oh, are there any other girls?&quot; And so, you go over and say, &quot;Hi,&quot; and then you try and tend to work with them just 'cause it’s a little bit less intimidating than working with other guys, or working with guys.</td>
</tr>
</tbody>
</table>
| Co-awareness                 | Confiding in female teammate(s) and, together, realizing gendered behaviour that is occurring in the team | F2: We were both noticing it [gendered treatment] separately and we could tell that we were both getting annoyed by it, so I don’t know who brought it up first, but we brought it up aside from the group and we talked about it, and realized the extent to which it was happening. Then we confronted the guys with it.  
F8: It’s definitely nice to have somebody who you could just be like, oh, did you hear how he just mansplained me? |
| Regret                       | Feeling disappointed for doing or (more often) not doing something in the project | F7: I wish that I had pushed a little harder to understand some of the parsing. |
| Self-doubt                   | Lacking confidence                                                         | F4: I felt like I was already kind of behind [of my other teammates] and trying to review everything with DNA sequencing and what not. |
The third category of codes is Behaviour. These themes represent ways that women act in teams, typically in response to the Feelings that they had. Several of the codes in this category have to do with task selection, describing why women do or do not take on project tasks.

Table 3. Codes pertaining to the Behaviour category.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Definition</th>
<th>Example(s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Making excuses</td>
<td>Defending the behaviour of a team member (typically male), often due to a friendship with that person</td>
<td>F7: I don’t take it super personally. I'm still friends with both of them [my male teammates]. And they're both definitely perfectionists. So, I can understand how it would be a little difficult to have that be a first instinct of like letting the less experienced people take the lead on things.</td>
</tr>
</tbody>
</table>
| Asserting herself      | Standing up for herself                                                     | F2: Maybe in the fact that a lot of times boys tend to trust what other guys are saying more, and then tend to challenge us a little more on our answers we give, and we need to prove it, almost, a little more than they just won't take our word for it. I've noticed that in other classes too, you have to push a little harder if you think your opinion is right, or you have a solution to the problem.  
F12: I feel like when there's another girl in the group, I'm more likely just to talk to her, but if I'm the only girl in the group, then I'm definitely a lot more outspoken, just because I feel like I need to be for them to hear me.  
F14: Initially the first time you get matched with a group there are inherent biases, so … if you have a comment you might have to be more aggressive about getting your voice heard. Really, that's only in the beginning, after that, once you've established that you know what you're talking about or you have rapport, it's fine after that. |
| Stereotypical tasks    | Taking on a role that is traditionally and stereotypically assigned to women (i.e. notetaker, secretary, scheduler, writer, etc.) | F8: We did most of the ... I like illustrated all the stuff in the game and she helped me with that.  
F10: Women are more organized than men… when we were researching, we would put everything on Google Docs so everyone could see it. A lot of the time, sometimes I would go through and make sure everything was nicely bulleted and all that stuff. I would definitely say that the other women in my group and myself, we would constantly go through the PowerPoint and make sure everything was perfect. The guys would not do that. |
| Unfavorable tasks      | A team member assigns a woman to do a specific task, despite her not wanting to take on that role | F2: Our lab group, the boys just would always just take control of whatever technical applications we're going in the labs. They wouldn't let us touch any of the equipment. We were not learning as much as we thought we could have. Then, when we came down to do the report, they just wouldn't do it and expect us to write up the report for them. But then we weren't really clear what to write up because they didn't let us do anything. |
To pick up slack | Taking on a task due to lack of effort or action from other team members | F5: They would just kind of choose the easier [sections of the report]. We never talked about it but I ended up having to write most of it.

Not Taking on Tasks

To improve team performance | Refraining from taking on certain project tasks for fear of negatively impacting the team | F7: People already knew how to surface mount things, or had already written scripts to parse data before, it was like they wanted to do it so they could do it super well, as opposed to letting the other guy and I who had not done quite as much before try it out and learn from it, like with the risk of it not turning out perfect.

Due to lack of experience | Not doing a project work because she perceives that she has less experience than the other group members | F4: I felt like I didn't really have a background in a lot of them and a lot of the other kids felt more comfortable doing so, so I just kind of let them take over.

Conclusion

The codebook developed in this work serves as a preliminary view into the experiences of female engineering students that could contribute to their dissatisfaction as they engaged in a first-year engineering design team project. In an attempt to investigate why female students are statistically significantly less satisfied in teams when paired with other women (as opposed to when they are isolated in teams), fourteen female engineering students were interviewed about their project experiences. After analysis, a codebook emerged that contained themes that pertained to three aspects of female engineering student experiences: Treatment, or how women perceived that they were treated in project teams; Feelings, or the emotions that women experience while working on projects; and Behaviours, or the ways women act in response to how they feel on project teams, particularly with regards to tasks that they do or do not take on.

Implications

Although the work here is a work-in-progress, it does elucidate implications for engineering education. The first implication – originally motivated by the quantitative findings that inspired this work, but then supported by the diverse range of interview responses from female students – is that every student is complex, and best practices for team formation may not apply to every team or, more specifically, every female student. Even with the good intentions behind pairing female students up on teams, women may end up being less satisfied with their team for a variety of reasons. Although it is likely not yet comprehensive, the codebook presented here identifies many reasons as to why women may be dissatisfied in teams. Instructors should aim to eliminate or avoid the Treatments that can lead to female students’ dissatisfaction and seek to provide scaffolding in the project to ensure that women are not able to fall into typical Behaviours that they may exhibit when dissatisfied in teams.

A second implication is that a dissatisfying team experience can, in fact, lead to some positive experiences. Some positive Feelings or Behaviours were reported by women on teams, even when they were dissatisfied with their team. For example, the Feeling of Co-Awareness may be uncomfortable, but ultimately is likely to be a positive, illuminating experience for students: in Co-Awareness, female students confide in each other to discuss their team dynamics, and in turn realize poor gender dynamics or negative Treatment that they may not have recognized on their own, and thus female students become more aware of gender dynamics at play in engineering teams. Another example of a positive outcome is the Behaviour of Asserting Herself, in which a woman who feels dissatisfied on their team
then uses that frustration to band together with other female team members to enforce their voice and role on their team.

**Future Research Plans**

This work-in-progress study has set the foundation for many future research directions. Although we have yet to move toward a comprehensive answer to our research questions, we believe we have a foundation for moving forward to consider how dissatisfaction, Treatment, Feelings, or Behaviours may differ in teams of different gender make-ups.

Following this work, we would like to study a wider variety of student experiences, and be able to determine how various elements of dissatisfaction identified here link specifically to the gender makeup of the team and/or project context. We would like to see how often female students experience these Treatments and Feelings and exhibit these Behaviours across other universities and project experiences, and determine how these experiences are linked to teams of specific gender makeup. We would like to use the findings presented here to aid us in development of a survey, in which we are planning on asking students to identify the gender makeup of their most recent engineering team before reflecting on that specific teaming experiences in answering closed-ended Likert-scale questions. This will allow us to determine if there are correlations between the gender makeup of the team and experiencing certain Treatments, Feelings, or Behaviours.

A second research direction is to gain more perspective on the team dynamics from the point of view of male students. Five male students were interviewed as a part of this study, but the interviews have not yet been analysed. We believe it is important to also understand how (or if) male students think about female students, and their dissatisfaction, in their engineering teams.

**Acknowledgment**

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Integrating Computation into a Civil Engineering Curriculum Instructions at a Colombian Higher Education Institution

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Abstract: This paper presents a work in progress to integrate computation across the civil engineering curriculum at a Colombian University. Engineering programs all around the world have started to realize the value of preparing the future professionals with the knowledge and skills to solve complex problems using computational tools and methods such as modeling and simulation. The paper describes the challenges the institution is facing with these courses, propose an instructional approach to support student learning, and presents a preliminary data analysis for the adaptation of an instrument that will allow to assess students’ self-beliefs about computing in the context of this curricular innovation.

Introduction

Computation has become an important tool for engineers and scientists to solve problems in their disciplines. Several researchers, reports, and industry representatives have suggested that everyone should develop computational thinking, defined as the thought process of formulating problems so that these can be solved by a computer (Barr & Stephenson, 2011; NRC, 2011; Royal Society, 2012). At the same time, several engineering disciplines (e.g., materials science and engineering) have created a subdiscipline (e.g., computational materials science) focused on using computation to solve complex problems in their field (Spanos, Allison, Cowles, Deloach, & Pollock, 2013). Computation enables engineers to process large amounts of data and represent complex phenomena through models and simulations (Lee et al., 2011). Note that computation and computational thinking goes beyond just programming, and includes concepts such as modeling and simulation, data visualization, and using existing computational programs and packages to solve problems (Vieira, Magana, Roy, & Falk, 2019; Weintrop, Beheshti, Horn, Orton, Jona, Trouille, & Wilensky, 2016).

Despite the relevance of computing across disciplines, computation is often taught in engineering programs isolated from the discipline and offering single opportunities to experience it (PITAC, 2005). Several engineering programs only include one programming course at the beginning of the plan of studies. Hence students do not experience these concepts again unless an instructor sees the value of using it into his/her classroom. As a result, students may learn concepts such as loops or functions on this unique experience, but they may not learn how they can use it to solve problems within their disciplines. Moreover, they fail to see the value of computing within their field, and might not intentionally pursue additional courses and experiences to improve their skills. This results in students feeling unprepared to use computation later in graduate school and in the industry.

Initial efforts to integrate computation within science and engineering disciplinary curricula have included the creation of courses in computing for specific engineering disciplines, creating computational modules for existing core engineering courses, creating
concentrations in computational science and engineering, and using visualization tools as a vehicle to explain complex phenomena and integrate computation within existing courses (Turner et al., 2002; Wofford, 2009; Vieira et al., 2018). These experiences have shown that learning computation integrated into mathematical modeling without having the required domain knowledge may be challenging for students (Magana, Falk, & Reese, 2013).

This paper describes the initial steps to integrate computation into a Civil Engineering program at a Colombian University. In this context, we started adapting an instrument to assess student’s self-beliefs about computing. The guiding research questions are:

- How can computing courses in civil engineering be transformed using evidence-based pedagogical practices to reduce student attrition and increase student performance and interest in computing?

- How can we measure students’ self-beliefs about computing in the context of civil engineering?

**Background**

The Civil Engineering Department at [Institution concealed for blind review] is organized, for development purposes, into academic areas. Each one of these basic units typically involves: (1) the coordination of both, undergraduate and graduate level courses; (2) participation in activities of a specific research group or within a more general research group; and (3) development of a so-called young or seed research program. The area of Computational Mechanics was formally introduced into the program in the year 2006 following a recommendation from the department faculty members and aimed at strengthening the consulting capabilities of the Institution’s prospect engineers. The area comprises two undergraduate (sophomore level) courses namely, Continuum Mechanics (CM) and Computational Modeling (MO); and two graduate courses Advanced Continuum Mechanics (ACM) and Introduction to the Finite Element Method (FEM). The graduate courses provide the initial theoretical basis for a master’s degree program and its potential extension into the PhD program. These courses are also available as elective courses at the senior level in the undergraduate program. At the undergraduate level, the Continuum Mechanics course has as a general and main goal providing the civil engineering students with a strong physical basis required to assimilate knowledge from areas based upon the principles of applied mechanics. These involve courses such as fluid mechanics, soil mechanics, solid mechanics, and structural analysis.

In parallel, the Computational Modeling course seeks to provide the students a minimum level of computing literacy, and particularly modeling abilities which are known to be required in current and modern engineering workplaces (Emmot and Rison, 2008; McKenna, & Carberry, 2012). It has also been the intention of the Department to promote the use of these acquired modeling skills in the follow-up core courses of the program.

Although there is a widespread perception among the civil engineering students that both undergraduate courses in the area imply an important level of academic commitment, the CM course exhibits dropout rates that have oscillated between 60% and 70% over the last 10 years. The instructors hypothesize that one of the main factors influencing those figures corresponds to a weak preparation of the incoming students at the basic sciences level and the fact that the conceptual construction of the continuum mechanics model requires a firm basis in fundamental physics and mathematics, expected to be provided during the freshmen year. This hypothesis is supported by the results from initial conditions tests conducted on the second week of the academic semester with only near 20% of the enrolled population obtaining a satisfactory grade. The initial conditions test evaluates the student capabilities in basic sciences subjects such as Calculus, Statics, Dynamics and Vector Analysis. On the other hand, although the dropout levels in the MO course is not as high (near 40% since its formal insertion into the program) as in the CM class the numbers are still considered high when compared with general university figures. The instructors of the course have also
identified the lack of logical thinking among the students as one of the main difficulties, a challenge for the development of subsequent programming skills.

Overall, the same difficulties persist over the graduate courses, although the levels of performance of enrolled graduate students is substantially higher as compared to the one from external incoming students. The goal of this project is to support student learning and to have a positive impact on students’ self-beliefs about computing in these courses of Computational Mechanics.

**Conceptual Framework**

Two frameworks will guide the design of the learning environments for these courses. Constructivism will guide the implementation of a flipped classroom approach with active learning. Constructivism suggest that learning depends on prior knowledge, and it is built on top of it (Hoover, 1996). This implies to turn the responsibility of the learning process to the student, using active learning activities (Brandon & All, 2010). The implementation of active learning was originally informed by the theory of constructivism, which suggest that we learn by connecting the new material to prior knowledge. Overt learning activities where students actively engage with the learning materials have demonstrated to be more effective than passive ones, especially if these activities become constructive or interactive ones, where students generate products that go beyond the materials (e.g., summaries, concept maps, self-explanations) (Chi, 2009). The implications of this framework for this study is the use of flipped lectures (Zabala et al. 2017) as pedagogical strategy.

Cognitive load theory (CLT) (Sweller, Ayres, & Kalyuga, 2011) will guide the integration of scaffolding strategies to support student learning in such complex learning environment. CLT describes how we learn these complex concepts and skills using a cognitive architecture with a working memory and a long-term memory. The working memory is limited in time and space, while the long-term memory is vast. This means that new material will only stay in our memory if we connect it to previous knowledge stored in the long-term memory. This also means that the students may be overwhelmed if they need to learn too many interacting elements at once. Instructional strategies such as worked-examples can be effective to manage such complexity when properly integrated (Atkinson, Derry, Renkl, & Wortham, 2000).

Integrating computation and computer programming within engineering disciplinary courses may overwhelm students (Magana, Falk, & Reese Jr, 2013; Vieira, Magana, Falk, and Garcia, 2017). Computer programming comprises a set of skills and concepts that are complex to learn (Mselle, & Twaakyondo, 2012). When learning computer programming, novices need to learn algorithm design, syntax and semantics of the programming language, how the computer works, and the program itself (Du Boulay, 1986). When integrated into disciplinary engineering, learning computation may become even more complex, by adding the interacting elements of mathematical modeling and domain knowledge (Magana, Falk, & Reese, 2013). Previous experiences have demonstrated that providing worked examples implementing a self-explanation strategy can help students to handle this complexity (concealed for blind review). This approach also allows to deal with the uneven expertise in a programming course. The implications of this framework is the integration of worked-examples in the form of Jupyter Notebooks, with a self-explanation activity to engage students in the active exploration of the examples.

**Theoretical Framework**

Control-value theory (Pekrun, 2006) is the theoretical framework that guides the development and adaptation of an instrument to assess students’ self-beliefs about computing. Self-beliefs correspond to individuals’ opinions about their attributes and skills, and some studies have demonstrated that students’ self-beliefs can have a significant effect
on academic achievement, and on the choices engineering students make (Valentine, DuBois, & Cooper, 2004). The Control-Value theory suggests that students’ emotions can affect the individual’s cognitive resources, motivation, and metacognition, which can have an impact on academic achievement and student engagement (Pekrun, 2006). These emotions depend on students’ perceived control on the outcome of a task and the perceived value or relevance of the task for students. While there are several validated instruments in English to assess students’ self-beliefs about computing (e.g., Magana et al., 2016; Scott, & Ghinea, 2014), there is no instrument to assess these construct in Spanish. This study adapted items from two existing instruments that used the Control-Value theory to explore student control and value to use computation at the undergraduate level (Magana et al., 2016; Scott, & Ghinea, 2014).

The Computational Learning Environments

Considering these frameworks to guide the pedagogical strategies and the scaffolding for the learning environment, we used the instructor’s guide for teaching and learning computational modeling and simulation in STEM (concealed for blind review). This guide was developed by educational researchers with experience in integrating computational thinking into engineering curricula, with the goal of supporting new faculty interested in implementing these curricular innovations. The guide suggests establishing specific learning objectives for the disciplinary (i.e., domain) component, and for the computational (i.e., modeling and simulation) component. The suggested organization of the teaching methods and instructional events is guided by the cognitive apprenticeship model (Colins, Brown, & Newman, 1989), where students become proficient on using computational tools for civil engineering problems. The cognitive apprenticeship model proposes integrating four dimensions to support student learning of content and skills, while promoting student motivation of the learning tasks: Content, Method, Sequencing, and Sociology. The content being taught corresponds to the integration of computational modeling tools and methods into civil engineering courses, with the goal of solving complex problems within this discipline. The instructional method describes the pedagogical characteristics of the learning environment. In this case, we use a flipped-classroom together with Python Notebooks to promote active learning in the classroom. The sequence describes the procedures and how the learning activities are organized, considering the level of complexity, diversity, and the scope. The dimension of sociology suggests promoting collaborative learning but also designing learning activities that have direct impact on real-world settings and are related to the intrinsic motivation of the students. The cognitive apprentice model has been previously used in civil engineering with positive outcomes on student learning (Poitras & Poitras, 2011). The guide to integrate computational modeling and simulation into engineering courses is presented in the next section including a sample learning environment.

A Sample Learning Environment

Here we describe the implemented learning environment for the graduate course Computational Modelling (MOD). This course involves theoretical and computational concepts and is imparted in a flipped classroom environment. For that purpose, the area of Computational Mechanics has developed several resources: (i) a set of lecture notes summarizing most of the theoretical contents and organized to meet specific class needs, (ii) a set of jupyter notebooks used as supporting material during the in-class sessions (iii) SolidsPy a Python based in-house finite element code for two dimensional elasticity problems and (iv) a Python based elasticity solutions visualization tool.

The Lecture Notes and Jupyter notebooks are related in such a way that during the in-class session the instructor uses the notebook to review and refresh the theoretical concepts previously covered by the students outside the class. The initial review by the instructor is
generally complemented by different in-class activities also covered in the notebook. The specific notebook for this learning environment simultaneously addresses two learning goals. First, it supports the disciplinary topic of Lagrange interpolation and second it helps, starting almost from scratch, novice students to start building basic Python programming skills. The notebook has several mixed activities such a commented sample problem, its Python solution and related quick answer questions. It also contains a glossary of terms intended to help the student start building the proper language and it concludes with an in-class activity intended to be developed by the students with a coaching technique on part of the instructor.

1. **Name of the topic or unit**: Introduction to one-dimensional interpolation.

2. **Learning Objective**
   A. Develop interpolation schemes to approximate, scalar and vector functions of different order.
   B. Develop basic Python programming skills as required for the solution of problems of approximation of functions in terms of interpolation theory.
   C. Implement interpolation schemes for scalar, vector and tensor valued functions in different physics and engineering contexts using Python.

3. **Specific disciplinary learning objective(s) of the assignment**.
   A. Employ the Lagrange based interpolation technique to approximate different functions and recognize its advantages in the formulation of numerical methods of solution to boundary value problems,
   B. Compare the quality of the Lagrange based interpolation technique in the approximation of functions and of its derivatives.
   C. Implement the Lagrange based interpolation scheme in the standard form used in various numerical methods.

4. **Specific (modeling and simulation) practices**
   Students extend the Lagrange Python function available in the provided NB by implementing the code in an independent script using storage and data structures typically used in different numerical methods for the solution of boundary value problems.

5. **Assessment strategies and grading system**
   An independent implementation in a Jupyter Notebook that will evaluate the student’s ability to solve interpolation problems in different physics and engineering contexts.
   A. Notebook organization and documentation (10%).
   B. Interpolation scheme at a local point is coded as an independent subroutine (10%).
   C. The subroutine performs well (70%).
   D. Appropriate plots of the interpolated function and its derivatives (10%).

6. **Guidance materials and resources**:
   A. Lecture notes.

7. **Instrumentation and software tools**: Code snippets available in the provided NB.

8. **Specific instructional events**.
A. **Method (modeling):** After students have prepared for the classroom session, the instructor will review some basic theoretical aspects of Lagrange based interpolation. The review is strongly related to the more detailed discussion available in the Lecture Notes. Then, the instructor will demonstrate how to implement a general function or subroutine in Python using an example in the Notebook. Such a function is later used in the computation of Lagrange Polynomials and a function approximation obtained via interpolation. Once the example is fully covered the NB presents to the student an independent in-class activity.

**Sequencing of activities:** In preparation for the class the students will independently cover the theoretical material of Lagrange interpolation using the set of Lecture Notes provided by the instructor and selected textbooks.

At the beginning of the in-class session there will be a quiz to evaluate simple theoretical concepts based on questions available in the Lecture Notes. After the in-class quiz the instructor will review the basic theoretical background focusing in the Lagrange interpolation theorem and the properties of Lagrange polynomials using a Jupyter Notebook where these concepts are summarized.

Subsequently, students will work on the same Jupyter notebook as a worked example, and students will write comments within the code to self-explain the provided example. This will engage them in the active exploration of the examples, while the instructor walks around the classroom to answer questions and to provide scaffolding when needed.

The students are then instructed to work individually in the creation of their own independent scripts and apply them in the interpolation of several functions and its first order derivatives as typically required in the approximation of functions in several numerical methods for the solution of boundary value problems.

At the end of the in-class session the students are instructed to group in couples, share implementations and consolidate solutions in a single Notebook.

9. **Homework.**

The students will solve an interpolation problem through a Python implementation in an independent Jupyter Notebook.

**Preliminary Data**

This project translated and adapted items from two existing surveys to assess students’ self-beliefs about computing (Magana et al., 2016; Scott, & Ghinea, 2014). The first instrument (Magana et al., 2016) was designed to assess students’ control on the outcome when using computation, and the value they perceived of computing in their own program. The second instrument (Scott, & Ghinea, 2014) was designed for an introductory programming course (CS1) and measured the constructs of debugging self-efficacy, programming self-concept, programming interest, programming anxiety, and programming aptitude mindset. Both instruments were supported by the Control-Value Theory (Perkin, 2006). Our instrument is designed to measure students’ self-efficacy, interest, and self-concept about programming. Table 1 describes the items in Spanish and in English that we hypothesized would measure each construct.

Fifty-eight civil engineering students enrolled in the Computational Modeling course completed the instrument at the beginning of the spring semester 2019. Eight students were in sophomore year, 32 students were in junior year, and 18 students were in senior year. Five students had taken at least one course in computing during high school, and two students had taken an online course in programming.
<table>
<thead>
<tr>
<th>Construct</th>
<th>Item</th>
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<tbody>
<tr>
<td>Self-efficacy</td>
<td>Q1 - Poseo la habilidad para resolver problemas matemáticos a través de programación / I have the ability to solve Math problems using programming</td>
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<td>Q2 - Poseo la habilidad de implementar algoritmos / I have the ability to design an algorithm.</td>
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<td>Q3 - Poseo la habilidad de crear un programa de computador / I have the ability to write a computer program.</td>
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<td>Q4 - Poseo la habilidad de crear visualizaciones de datos a través de la programación. / I have the ability to visualize data using a computer</td>
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<td>Q5 - Me siento confiado para resolver problemas simples con mis programas / I am confident I can solve simple problems with my programs</td>
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<tr>
<td>Interest</td>
<td>Q6 - Planeo tomar cursos que me permitan incrementar mi conocimiento en programación / I intend to purposefully seek courses that will allow me to increase my knowledge about computation.</td>
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<td></td>
<td>Q7 - Siento que la programación será útil en mi carrera como profesional / I feel computation will be useful in my career.</td>
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<td></td>
<td>Q8 - Siento que la programación es útil en mi programa académico / I feel computation will be useful in my studies.</td>
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<td></td>
<td>Q9 - Creo que programar es interesante / I think programming is interesting</td>
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<td>Q10 - Me interesan las cosas que aprendo en los cursos de programación / I am interested in the things I learn in programming classes</td>
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<td>Q11 - Yo hago programas de computador porque lo disfruto / I do programming because I enjoy it</td>
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<tr>
<td>Self-concept</td>
<td>Q12 - Siempre he creído que programación de computadores es una de mis mejores áreas / I have always believed that programming is one of my best subjects</td>
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<td></td>
<td>Q13 - Aprendo a programar fácilmente / I learn programming quickly</td>
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<tr>
<td></td>
<td>Q14 - Yo, simplemente no soy bueno programando / I am just not good at programming</td>
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</table>

We used Pearson correlation across items to explore convergent and discriminant validity (DeVellis, 2016). Table 2 describes the resulting Pearson coefficients. The items in **bold** represent a strong correlation while items in **red** represent those items that did not show the expected relationship to the items measuring the same construct. We used Rubin’s (2012) guidelines to interpret this coefficient as follow: weak relation: |r| < 0.1; weak to moderate: 0.1 < |r| < 0.2; moderate: 0.25 < |r| < 0.35; moderate to strong 0.35 < |r| < 0.4; and strong: 0.5 < |r|. Since this is an initial exploratory phase in the instrument development with a limited sample of 58 participants, we will consider a moderate-to-strong correlation (0.45 < |r|) as an indicator of good convergent validity. Items Q1 to Q4 showed strong correlations among them, suggesting a good convergent validity for these items measuring students’ self-efficacy. These items also showed a good discriminant validity with the rest of the items in the scale. Likewise, the five items measuring students’ interest in programming (Q6-Q10), showed strong correlations among them, and weak to moderate correlations with the other
items. However, item Q13 (i.e., \textit{I learn programming quickly}) did show a moderate to strong correlation with the items measuring students’ interest in programming. These results suggest a relationship between students’ self-concept and interest, but there is not enough evidence to support this claim, since items measuring students’ self-concept did not depict the expected relationship among them.

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<thead>
<tr>
<th></th>
<th>Q1</th>
<th>Q2</th>
<th>Q3</th>
<th>Q4</th>
<th>Q5</th>
<th>Q6</th>
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<th>Q8</th>
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<th>Q11</th>
<th>Q12</th>
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<td>Q1</td>
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<td>Q2</td>
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<td>Q3</td>
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<td>Q4</td>
<td>0.58</td>
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<td>Q5</td>
<td>0.41</td>
<td>0.47</td>
<td>0.29</td>
<td>0.39</td>
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<td>Q6</td>
<td>0.09</td>
<td>0.23</td>
<td>0.05</td>
<td>0.22</td>
<td>0.32</td>
<td>1.00</td>
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<tr>
<td>Q7</td>
<td>0.15</td>
<td>0.23</td>
<td>0.12</td>
<td>0.29</td>
<td>0.17</td>
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<tr>
<td>Q8</td>
<td>0.12</td>
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<td>Q10</td>
<td>0.09</td>
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<td>-0.01</td>
<td>0.13</td>
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<td>0.22</td>
<td>0.18</td>
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<td>0.23</td>
<td>0.04</td>
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<td>Q13</td>
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<tr>
<td>Q14</td>
<td>-0.13</td>
<td>-0.22</td>
<td>-0.30</td>
<td>-0.07</td>
<td>-0.10</td>
<td>0.17</td>
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<td>0.25</td>
<td>0.16</td>
<td>0.07</td>
<td>-0.07</td>
<td>-0.22</td>
<td>-0.14</td>
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Further analysis for internal consistency showed a strong Cronbach alpha (Cortina, 1993) for students’ self-efficacy (alpha = 0.86) and for students’ interest about programming (alpha = 0.86) but not for students’ self-concept (alpha = 0.56). Together, these results suggest that items Q1-Q4 are effectively measuring students’ self-efficacy and items Q6-Q10 are effectively measuring students’ interest in computation, but the items, Q5, and Q11 to Q14 need to be further validated.

**Conclusions and Future Work**

This paper described a work in progress to integrate computational sciences across the curriculum of Civil Engineering. These courses have demonstrated to be very challenging for students, with dropout rates ranging from 60% to 70%. The main contribution of this paper is the research-informed design of a learning environment that integrates computation within a civil-engineering program. The research team used the theories of constructivism and cognitive load theory to inform the pedagogical strategies to support students in these courses. Constructivism supports the integration of the flipped classroom methodology, where students work collaboratively to solve problems in the classroom. The Cognitive Load Theory supports the integration of examples in the form of Jupyter Notebooks, including self-explanation activities in the form of in-code comments. These two strategies were integrated into a Cognitive Apprenticeship model for the course instructor to identify the content as the learning outcomes for the domain knowledge and the modeling and simulation knowledge, teaching method, sequencing of activities, and the sociology of the course.

The next steps in this project involve an evaluation of the proposed learning environment, identifying the affordances and challenges of this approach to support student learning for such complex learning environment. Regarding the instrument development, additional data
is required in order to further validate the instrument using factorial analysis. However, items Q11 to Q14 should be revised to ensure convergent and discriminant validity.

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Gamification of a flipped classroom course: effects in students’ motivation and learning

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Abstract: Motivated students are more committed with their learning. Flipped classroom and gamification are two techniques that have shown to be effective to improve motivation of engineering students. Will these effects increase by combining both techniques? A comparative study between two sections of engineering course was carried out: one using a flipped classroom approach (FS) and another using both (GS). Questionnaires were applied in week 3 (T1) and during the final week of the semester (T2) to measure the students’ motivation and their assessment of the methodology. At the end of the course the students performed a written exam. The results show no significant differences on students' motivation and learning between sections. This result could be explained to a negligible effect of gamification in flipped classroom courses. Moreover, the fact that GS students consider that they would have better performance with the FS methodology suggest that several instructional changes could have caused an overwhelming effect.

Introduction

Motivated students are more committed with their learning because they will actively seek the information and understandings that constitute engaged learning (Admiraal, Wubbels & Pilot, 1999; Barkley, 2010). Thus, to improve learning of engineering students it is important to study how to increase their motivation (Lombardi & Oblinger, 2007). The design of new learning methodologies is a response to this need, being the motivation and commitment of the students important goals considered in the design of these methodologies (Karabulut-Ilgu, Jaramillo Cherrez & Jahren, 2018).

In recent years, flipped classroom is one of the most popular learning methodologies used to improve student engagement in engineering education (Karabulut-Ilgu, et al., 2018). Several studies have shown it has positive effects in students’ engagement and learning (Lavelle, Stimpson & Brill, 2013; Chiang & Wang, 2015; Ossman & Warren, 2014; Schmidt, 2014; Day & Foley, 2006; Moravec, Williams, Aguilar-Roca, & O’Dowd, 2010). Flipped classroom principles are that students study from online materials prior to the class. Then in-class they reinforced their learning through solving related problems with teacher supervision (O’Flaherty & Phillips, 2015).

Gamification is another technique that has been shown to improve motivation and commitment in higher education (Tsay, Kofinas. & Luo 2018; Zainuddin, 2018; Buckley, Doyle, E. & Doyle, S., 2017). This technique uses game-design elements in non-game contexts (Deterding, Dixon, Sicart Nacke & O’Hara, 2011). The application in education, includes the usage of specific game-design elements inside the learning process, such as:
points, leaderboards, challenges, badges, among others (Sailer, Hense, Mayr & Mandl, 2017; Dicheva, Dichev, Agree & Angelova, 2015).

Flipped classroom and gamification could be complementary techniques. Since both have shown positive effects on students’ motivation in higher education: Will this effect increase when both techniques are combined?

This study analyzes the effects in students’ motivation and learning, after applying gamification to a flipped classroom engineering course.

**Methodology**

A comparative study between two sections of a database course was carried out: the first using a standard flipped classroom approach (FS) with 51 engineering students, and the other including gamification and flipped classroom (GS) with 52 students of the same degree. Both sections were taught on the same semester and at the same schedule, sharing the course material and class activities.

The following sections gives more in-depth details of the methodology used for this study. First, an explanation of the instructional design of each course section. Then, the details of the Virtual Learning Environments (VLE) used for each sections are presented, allowing to identify the game-design elements incorporated to the GS. Finally, the questionnaire design used to measure the students motivation with the course is shown.

**Instructional Design**

Figure 1 shows the instructional design for both sections with all the activities that students must perform weekly. The difference between the sections was in the second activity, where the FS students complete a weekly quiz with 12 to 15 questions the day before the class, while the GS students had 4 quizzes with 3 to 5 questions each, one quiz per workday except the day of the class. The questions database was the same for both sections.

To gamify the GS, the following game-design elements were incorporated:

- **Stages**: the semester was divided in 12 stages of one week duration. FS used the same weekly partition.
- **Points**: grades were transformed into points.

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Figure 1. Course methodology for both sections (FS = Flipped Section, GS = Gamified Flipped Section). Step 2 is the only different activity between sections.
● **Leagues**: three leagues were defined, dividing the students according to their results in the previous stage. The leagues were used only for the online activities not for the in-class activities.

● **Leaderboards**: global leaderboard and leagues leaderboards were visible to all GS students.

● **Badges**: students obtained a badge when they reached some defined goal (e.g. stage league winner, first student in answer correctly all question of a challenge). Each badge gave points to the student.

● **Challenges**: online quiz and in-class activities were transformed into challenges. Challenges defined a goal (amount of correct questions) and points to be rewarded.

● **Performance**: The GS student could see the evolution of his performance (i.e. points earned) in the previous stages.

**Virtual Learning Environment (VLE)**

Figure 2 shows the student view of the VLE used in FS. This VLE had all the features needed to apply a flipped classroom methodology: permanent access to the course study material, forums for questions and discussions, online quizzes and assignments. On the other hand, Figure 3 shows the student view of the VLE used in GS. This second VLE had the same features as the FS VLE, but in a gamified context, incorporating the game-design elements described in the Instructional Design.

![Figure 2](image-url) **Figure 2. Student view of the VLE used by Flipped Section (FS) students.**
Instruments

A questionnaire was developed to measure students’ motivation and their assessment of the course methodology. Motivation was assessed with the Intrinsic Motivation Inventory (IMI; Ryan, Mims & Koestner, 1983) using 4 of its variables: Interest/Enjoyment (IE), Perceived Competence (PC), Value/Usefulness (VU), and Effort (EF). The version of IMI used in this study has 13 items, which were measured on a 7-point Likert scale from 1 (strongly disagree) to 7 (strongly agree).

<table>
<thead>
<tr>
<th>Variable</th>
<th>Source</th>
<th>Example of items</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest/Enjoyment (IE)</td>
<td>IMI</td>
<td>- I enjoyed doing course activities very much.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- I thought this was a boring course.</td>
</tr>
<tr>
<td>Perceived Competence (PC)</td>
<td>IMI</td>
<td>- I think I am pretty good at this course.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- I am satisfied with my performance at this course.</td>
</tr>
<tr>
<td>Value/Usefulness (VU)</td>
<td>IMI</td>
<td>- I believe this course could be of some value to me.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- I think that doing this activity is useful for an engineering.</td>
</tr>
<tr>
<td>Effort (EF)</td>
<td>IMI</td>
<td>- I put a lot of effort into this course.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- I didn’t put much energy into this course (reverse).</td>
</tr>
<tr>
<td>Methodology Evaluation (ME)</td>
<td>Own definition</td>
<td>- I would do a course again with this same methodology.</td>
</tr>
<tr>
<td>Other Section Perceived Usefulness (OU)</td>
<td>Own definition</td>
<td>- I feel that I would have obtained better grades with the methodology used in the other section</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- I think I would have learned more with the methodology used in the other section</td>
</tr>
</tbody>
</table>

To measure the students satisfaction with the methodology of their section two more variables were incorporated: Methodology Evaluation (ME) and Other Section Perceived Usefulness (OU). ME was assessed with only one item asking students if they would do another course with the same methodology. OU was measured with 3 items about the
students' perception of their performance if they had been in the other section. These new items used the same IMI Likert-scale.

Table 1 presents examples of items used in the questionnaire to measure the six variables. Questionnaires were applied in week 3 (T1) and during the final week of the semester (T2). OU items were used only in T2 questionnaire.

Additionally, at the end of the course the students of both sections performed the same written exam. The exam results were used to compare learning outcomes.

Findings

Two different types of groupings were made to compare the questionnaire results. First, a comparison between the results in T1 and T2 for each section was done. Then, a comparison between the results of each section for each questionnaire instance. The Figure 4 shows the results obtained for each instance of the questionnaire in each section. Additionally, these results are displayed in 4 different scenarios so that it allows to visually compare the values obtained.

Figure 4. Comparisons of questionnaires results. (a) Compare T1 with T2 for Gamified Flipped Section. (b) Compare T1 with T2 for Flipped Section. (c) Compare T1 between both sections. (d) Compare T2 between both sections.
To validate the existence of significant differences a t-test between the results of the different variables for the four different scenarios was performed. These results are shown in Table 2.

Table 2. Results of t-test (p-values) for the four different scenarios. Significant differences are in bold font.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Group 1</th>
<th>Group 2</th>
<th>IE</th>
<th>PC</th>
<th>VU</th>
<th>EF</th>
<th>ME</th>
<th>OU</th>
</tr>
</thead>
<tbody>
<tr>
<td>a</td>
<td>GS-T1</td>
<td>GS-T2</td>
<td>0.281</td>
<td>0.014</td>
<td>0.025</td>
<td>0.032</td>
<td>0.789</td>
<td>-</td>
</tr>
<tr>
<td>b</td>
<td>FS-T1</td>
<td>FS-T2</td>
<td>0.383</td>
<td>0.274</td>
<td>0.039</td>
<td>0.02</td>
<td>0.037</td>
<td>-</td>
</tr>
<tr>
<td>c</td>
<td>GS-T1</td>
<td>FS-T1</td>
<td>0.347</td>
<td>0.521</td>
<td>0.862</td>
<td>0.279</td>
<td>0.199</td>
<td>-</td>
</tr>
<tr>
<td>d</td>
<td>GS-T2</td>
<td>FS-T2</td>
<td>0.135</td>
<td>0.407</td>
<td>0.634</td>
<td>0.169</td>
<td>0.877</td>
<td>0.016</td>
</tr>
</tbody>
</table>

When comparing the results between T1 and T2 for the GS students, we found a significant difference in some IMI variables: Perceived Competence (PC) and Effort (EF) increased, while Usefulness (VU) decreased during the semester. In the case of the FS students, there was a significant increase in Effort (EF) and a significant decrease in Usefulness (VU). Also, the FS students had a significance decrease in their interest to do another course with the same methodology (ME), although its average remained similar to that of GS students.

No significant differences were found between the GS and the FS with respect to IMI variables neither in T1 nor in T2. So the previously demonstrated positive effect of gamification in students motivation seems to be diluted when applied it in a flipped methodology.

![Figure 5. Histogram with exam results.](image)
There was a significant difference between sections on the perception of the students about
their performance if they had been in the other section. The GS students considered more
frequently that they would have had better performance with the methodology of the other
section (see OU variable in Figure 4.d).

On the learning side, Figure 5 summarizes the exam results for both sections. There were no
significant differences in the exam performance between sections ($p = 0.703$).

Conclusions and Future Work

The results show no significant effect on students' motivation and learning by gamifying a
flipped classroom course. Although this conclusion differs from previous research, this
difference could be attributed to a negligible effect of gamification in flipped classroom
courses. Moreover, the fact that the GS students consider that they would have achieved
better performance with a flipped classroom methodology without gamification suggest that
the application of several instructional changes could have caused an overwhelming effect.

Also, it can be highlighted as an interesting result that the students of both sections had a
similar motivation during the semester, being mostly good values. This tends to confirm that
flipped classroom and gamification are techniques that have positive effects with engineering
students.

As a complex system that already reaches good results the effort to improve students’
motivation increases exponentially. For this reason, it is important that before making
adjustments to the learning methodology, an evaluation of the main variables that impact on
students’ learning is carry on in order to intervene the variable where the effort is more
rewarded.

In this study motivation was measured through the students perception. In a future work it
would be interesting to compare the participation in the online activities of the students in
each section to analyze the effects of gamification in participation, and if this is different than
the self declared motivation. This could be done by taking into account the interactions within
the VLE of each section.

References

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Literature Review: Exploring Teamwork in Engineering Education

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Abstract: Teamwork is considered a key skill in engineering, however, in engineering education there is no agreement on what are the attributes that promote effective teamwork. A systematic review of the literature was conducted and 26 papers were analysed. Results suggested that effective teamwork can be developed when the following 11 attributes are present: Shared Goal & Value, Commitment to Team Success, Motivation, Interpersonal skills, Open/Effective Communication, Constructive Feedback, Ideal Team Composition, Leadership, Accountability, Interdependence and Adherence to Team Process & Performance. Implications for practice and research are discussed.

Introduction

The Engineer of 2020 report highlights the importance of teamwork as a key engineering skill due to the increasing complexity and scale of the types of problems engineers solve. The students’ capability to effectively work in engineering teams is a highly regarded trait that potential employers in industry seek when looking to hire new talent into their organization (Hissey, 2000; Thomas & Busby, 2003; Smith & Imbrie, 2007; Passow, 2012). One of the Accreditation Board for Engineering and Technology (ABET) criteria is for students to have the ability to function in high performing teams. This requires universities to better prepare students with teamwork skills and to incorporate teamwork as an important part of engineering curriculum (ABET, 2017). This requirement by ABET and industry highlights the necessity of further exploring teamwork effectiveness by engineering education researchers.

Teamwork has been studied in engineering education for several decades. Specifically, according to the Engineers of 2020 report, NSF and the engineering community have been calling for systemic changes in engineering education with more emphasis on teamwork skills for the last 20 years (NAE, 2004). However, the field has not agreed on what teamwork means, and how to effectively teach it (Schmidt, 2006; Sheridan, Kinnear, Evans, & Reeve, 2015). As a result, many universities have failed to show that the use of teams in engineering students have enhanced their teamwork capabilities and learning outcomes (Adams, Simon Vena, Ruiz-Ulloa, & Pereira, 2002).

Engineering education literature has presented several strategies regarding how to ensure effective teamwork in engineering. The strategies used in engineering education literature focuses primarily on enhancing student teamwork capabilities and faculty responsibilities towards developing effective teamwork. Some strategies include development of a teamwork conceptual model by Davis & Ulseth (2013) highlighting four key areas of performance in classroom and conceptual model developed by Adams, Simon Vena, Ruiz-Ulloa, & Pereira (2002) to assess team effectiveness using seven characteristics. In addition to the models developed as strategies, Purzer, (2010) uses a strategy where students are given the opportunity to observe and learn from other teams and apply it in their own team. Other strategies include self-assessment and peer-assessment techniques to understand team effectiveness among students. (Ahmadian, 2011; Davis & Ulseth, 2013; M. P. K. Sheridan, Evans, & Reeve, 2012; Smith, Hoffart, & O’Neill, 2016; Helmi et al., 2016). However, with the
strategies used in engineering education, there is no clarity on which ones are more effective promoting the desired skill necessary for teamwork effectiveness.

This situation suggests the need for enhanced theoretical and conceptual foundations to develop effective teamwork in engineering education. The purpose of this study is to conduct a systematic review of the literature to understand what attributes make teamwork effective in engineering education. Therefore, this study addresses the following research question,

RQ: What aspects of teamwork have been proposed or studied in order to ensure effective teamwork among engineering students?

Literature Review

Teamwork in Engineering Education

Since teamwork is an important skill required by ABET and potential employers in industry, engineering educators have conducted several researches to ensure that students experience and enhance their learning outcomes in teamwork skills at different levels of their undergraduate phase. Following the work on effective teamwork by McGourty & Meuse (2000) and Reichmann (1998), Adams, Simon Vena, Ruiz-Ulloa, & Pereira (2002) developed an instrument, Team Effectiveness Questionnaire (TEQ) to assist in the development of team effectiveness by measuring the performance and attitude of each individuals. However, the TEQ instrument had limitations in terms of validation and reliability during implementation (Ruiz-Ulloa & Adams, 2004; Perez et al., 2006).

Another widely used tool for understanding teamwork effectiveness among team members is The Comprehensive Assessment of Team Member Effectiveness (CATME). The CATME tool was developed for students and faculty in engineering for the purpose of assessing teamwork in engineering classroom (Ohland, Pomeranz, & Feinstein, 2006). CATME helps students to function effectively in teams and also supports faculty in managing student team experiences (Loughry, Ohland, & Woehr, 2014). The CATME showed some limitations when implemented in different engineering classrooms involving teamwork. In one of the junior level product design class, the students were asked to use the CATME system by completing peer and self-evaluation in as a mean of improving teamwork effectiveness, but after using the system, only 25% of the students recommended its use as it was time consuming and less engaging in terms of teamwork effectiveness (Pung & Farris, 2011). Furthermore, learning benefits and the effects of using the CATME model on team processes and different team compositions have not been validated (Loughry et al., 2014).

Even though there are tools to use and assess teamwork in engineering classrooms, like the TEQ or CATME, there is no clarity in engineering education about how to use a teamwork model that is effective. Furthermore, engineering instructors do not receive training on how to teach teamwork but are expected to develop the skill in engineering students. Therefore, in this paper we explore the existing literature on teamwork to better understand what attributes are necessary to develop effective teamwork in engineering education.

Methodology

Criteria:

In this study a systematic literature review was conducted to identify teamwork attributes that make teamwork effective. Following Borrego et al. (2014) procedures for systematic reviews, we analyzed sources from book chapters, journals and conference papers using “Teamwork” as the search term. In the initial search, more than 100 were found. The literature found from these sources were initially explored through their abstracts. The selection criteria used to guide the review was to include papers that (i) included the implementation of a teamwork model, (ii) assessed teamwork effectiveness, (ii) that mentioned attributes and characteristics for teamwork to be effective. Out of our initial search for “Teamwork” from multiple
disciplines, we selected 26 scholarly papers that were used in this systematic literature review.

Data collection:
For the systematic literature review, we selected 26 scholarly papers from 18 Journals, 5 Book chapters and 3 Conference papers that fulfilled our criteria for the teamwork search. The major categories of the scholarly papers include (i) Business and Management, (ii) Education, (iii) Engineering Education and (iv) Psychology. From the Business and Management category, we found 13 journal papers and 4 book chapters, the Education category includes 4 journal papers, the Engineering Education category includes 3 conference papers and the Psychology category includes 1 journal paper and 1 book chapter.

Data Analysis:
After initially reviewing the abstracts of the papers, we started identifying different aspects of teamwork that we considered were important when developing teamwork skills in engineering students. We specifically used Borrego et al. (2014) procedures for systematic reviews to guide our systematic literature review on teamwork in engineering education. Several databases were used to locate the primary sources for ‘teamwork’. We used General databases including JSTOR and Scopus, Journal databases including Wiley, Science Direct, etc. and Gray literature databases including ASEE and IEEE conference proceedings and book chapters. After we selected 100 different sources in our primary search, our next step was to systematically assess the quality of the selected primary sources. We looked for key words in the scholarly papers which were relevant towards teamwork effectiveness. This step yielded 26 scholarly papers that were used in the final step of the systematic review. The final step was the synthesis of our systematic review which involved identifying the attributes for an effective team from the scholarly papers.

Results
According to (Imbrie, Maier, & Immekus, 2005), For a team to be effective, an individual must identify the attributes of a good team performance. In order to identify key themes for an effective team, we analysed 26 scholarly papers from multiple disciplines which mention teamwork attributes. From our systematic review, we were able to identify 11 teamwork attributes which were discussed as factors for enhancing teamwork effectiveness. The 11 key teamwork attributes are explained in this section in detail. Table 1 provides an overview of the attributes and the sources that cite them as an important aspect of effective teamwork.

<table>
<thead>
<tr>
<th>No.</th>
<th>Teamwork Attribute</th>
<th>Description</th>
<th>Authors</th>
<th>Discipline</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Shared Goal &amp; Value</td>
<td>Setting a common team goal and sharing values among team members. The shared goals and values should promote common rules, group cohesion and flexibility</td>
<td>Kets De Vries, 1999; Francis &amp; Young, 1979; Ziegler, 2003; Bradley &amp; Frederic, 1997; Riebe, Roepen, Santarelli, &amp; Marchioro, 2010; Scarnati, 2001; Harris &amp; Harris, 1996</td>
<td>Management, Engineering Education</td>
</tr>
<tr>
<td>2</td>
<td>Commitment to Team Success</td>
<td>Commitment to succeed in the group and receive prestige and recognition as a result of team’s success</td>
<td>Critchley &amp; Casey, 1986; Scarnati, 2001</td>
<td>Management</td>
</tr>
<tr>
<td>3</td>
<td>Motivation</td>
<td>Motivated and satisfied with their team task. Drive to succeed through positive perception</td>
<td>Kotey, 2007; Gardner &amp; Korth, 1998; Bradley &amp; Frederic, 1997; Wageman, 1997; Ziegler, 2003;</td>
<td>Business, Management, Education</td>
</tr>
<tr>
<td></td>
<td>Engineering Education</td>
<td></td>
<td>Business, Management</td>
<td></td>
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</tr>
<tr>
<td>4</td>
<td>Interpersonal skills</td>
<td>Respect and care for each other with high level of mutual trust among team members and have productive interactions to enhance task performance</td>
<td>Kets De Vries, 1999: Critchley &amp; Casey, 1986; Bird, 1989; Harris &amp; Harris, 1996</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>Open/Effective Communication</td>
<td>Engaging in open dialogue, timely communication and have value active listening skills. Members should also present work effectively to other team members.</td>
<td>Kes De Vries, 1999; Riebe, Roepen, Santarelli, &amp; Marchioro, 2010; Critchley &amp; Casey, 1986; Harris &amp; Harris, 1996; Bradley &amp; Frederic; Study &amp; Gantasala, 2015; Davis &amp; Ulseth, 2013; Ziegler, 2003;</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Constructive Feedback</td>
<td>Build a team spirit of constructive criticism where team members provide and accept feedback from each other in a positive and non-protective manner</td>
<td>Harris &amp; Harris, 1996; Ziegler, 2003; Druskat &amp; Kayes, 2000</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Ideal Team Composition</td>
<td>Team function including diversity, member roles, ideas, subject knowledge, etc</td>
<td>Bradley &amp; Frederic, 1997; Kotev, 2017; Harris &amp; Harris, 1996; Wageman, 1997; Critchley &amp; Casey, 1986</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Leadership</td>
<td>Leadership skills within the group. Includes taking leadership role through consensus of the team, acting as a facilitator, monitoring tasks, dealing with conflict and accomplishing tasks</td>
<td>Zeigler, 2003; Morgeson et al., 2010; Einstein &amp; Humphreys, 2001; Druskat &amp; Wheeler, 2003; Schiminke et al., 2002</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Accountability</td>
<td>Individuals are accountable for their share of work and also take personal responsibility in team tasks and actions assigned to them</td>
<td>Smith, 1996; Ziegler, 2003; Bracklin &amp; Williams, 2001</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Interdependence</td>
<td>Helping each other and promote individual contribution within the group. Learning together and supporting each other socially</td>
<td>Smith, 1996; Harris &amp; Harris, 1996; Bradley &amp; Frederic, 1997; Scarnati, 2001; Campion et al. 1993; Johnson, Heimann, &amp; O'Neill, 2000</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Adherence to Team Process &amp; Performance</td>
<td>Developing strategies/decision/solution through creative/feasible means and act to solve problems towards an effective work process</td>
<td>Cannon-Bowers et al. 1993; Valdez &amp; Kleiner, 1996; Wageman, 1997; Bracklin &amp; Williams, 2001</td>
<td></td>
</tr>
</tbody>
</table>

**Shared Goals and Values**

Kets De Vries (1999) identified that team members must share a strong common goal within the team in order to have effective teamwork. Francis & Young (1979) and Ziegler (2003) mention that each team member should be clear about their purpose within the team and make sure all the team members agreed on the shared goals. Team members who share common goals and values should promote regular interactions and promote group cohesion and have flexibility in terms of rules within the team (Bradley & Frederic, 1997; Riebe,
Roepen, Santarelli, & Marchioro, 2010; Scarnati, 2001). Kets De Vries (1999) gives importance to the values of a team mentioning that members should have strong shared values and beliefs in the team to promote teamwork effectiveness. In order to share strong values, the team atmosphere should also sometimes be informal, relaxed, comfortable, and non-judgemental (Harris & Harris, 1996).

**Commitment to team success**

According to Critchley & Casey (1986), for a team to be effective, each member must show strong commitment to succeed. Once a team succeeds in terms of accomplishment as a result of strong commitments, Scarnati (2001) emphasizes on giving prestige and recognition to each member in the team.

**Motivation**

Kotey (2007) and Gardner & Korth (1998) emphasize on motivation as a factor for teamwork effectiveness. According to them, a positive perception of a team enhances the team performance and members are motivated to commit to group performance. If team members are motivated, they are engaged, satisfied with their team task and drive to succeed in the team (Bradley & Frederic, 1997; Wageman, 1997). Furthermore, Ziegler (2003) mentions that team members are also motivated when they are recognized from their individual contributions within the team without expectations.

**Interpersonal Skills**

According to Critchley & Casey (1986) and Kets De Vries (1999), interpersonal skills among team members are strong when members of the team support each other, care for each other and have high level of trust amongst themselves. Harris & Harris (1996) also mentions that team members should be mutually respectful and supportive of one another and have mutual expectations in order to enhance task performance. Bird (1989) goes beyond the boundaries of workplace, mentioning that team interaction outside of workplace is essential in developing interpersonal relationship amongst team members and enhance task performance.

**Open and Effective Communication**

For a team to be effective, members should engage in open dialogue and communication by encouraging members to express group feelings and value active listening skills. (Kes De Vries, 1999; Riebe, Roepen, Santarelli, & Marchioro, 2010; Critchley & Casey, 1986; Harris & Harris, 1996; Bradley & Frederic). Conflicts within teams are very common, but an effective team will have members who open up when facing conflicts and try to resolve them (Critchley & Casey, 1986; Study & Gantasala, 2015). Emphasis was also given to effective communication to enhance teamwork effectiveness by Davis & Ulseth (2013) and Ziegler (2003). According to Davis & Ulseth (2013), when communicating external stakeholders, team members should establish, implement and revise protocols to ensure proper and timely communication. Also, individuals should organize and prepare their work prior to presenting formally or informally to the team members or supervisors in the team to ensure effective communication (Ziegler, 2003).

**Constructive Feedback**

For a team to be effective, all team members should acknowledge the purpose of feedback within the group. Team members should cultivate a team spirit of constructive criticism and authentic non-evaluative feedback (Harris & Harris, 1996). Feedbacks should be given positively to team members mentioning both strengths and improvement points for weaknesses (Harris & Harris, 1996; Ziegler, 2003). The member who is receiving the feedback should be attentive and accept the feedbacks in a positive and non-protective manner (Druskat & Kayes, 2000; Harris & Harris, 1996).
**Ideal Team Composition**

According to Bradley & Frederic (1997) successful teams are a product of appropriate team composition. For teamwork effectiveness, members should comprise of members who share brilliant ideas, have subject knowledge and can contribute within individual strengths (Kotey, 2017). In order to ensure contribution according to their strengths, members should clarify their roles, relationship assignments and discuss differences in what each member has to contribute to work (Harris & Harris, 1996; Wageman, 1997). Kotey (2017) also emphasizes on the diversity of team members, highlighting that a team should have an optimum level of diversity in order to promote new ideas and minimize conflicts amongst themselves to ensure teamwork effectiveness. An effective team will also have a team composition where decisions are by made consensus rather than individual views or disagreements (Critchley & Casey, 1986).

**Leadership**

Leadership is a very important attribute discussed in several scholarly papers as being a direct influence for teamwork effectiveness. According to Zeigler (2003), a team should establish a team leader using consensus of the entire team to ensure the functioning of an effective team. Morgeson et al. (2010), Einstein & Humphreys (2001), Druskat & Wheeler (2003) and Schiminke et al. (2002) highlights specific leadership roles to ensure teamwork effectiveness. Morgeson et al. (2010) mentions that team leaders should make plans for work accomplishments by giving each member responsibilities of their task depending on their strengths and give timelines for task completion. Einstein & Humphreys (2001) mentions that team leaders should provide regular feedback to the team members for different aspects including team performance, adaptation and learning and development. Furthermore Druskat & Wheeler (2003) and Schiminke et al. (2002) mentions that team leaders should respect individual’s idea, deal with conflict and interpersonal issues within the team positively and care for each individual member from time to time.

**Accountability**

To ensure teamwork effectiveness, when an individual task is assigned to team members, they should be accountable for their share of work by taking responsibility for their tasks and prepare to answer for the actions taken towards task completion (Smith, 1996; Ziegler, 2003; Bracklin & Williams, 2001).

**Interdependence**

According to Francis & Young (1979) group work in the team will result in better deliveries of task versus individual contribution. Hence, to ensure team effectiveness, team members should help each other while performing their assigned tasks (Smith, 1996; Harris & Harris, 1996; Bradley & Frederic, 1997). Interdependence in the team will be achieved when team members are not be self-directed and completely individual in their work, rather they support each other socially and learn together so that each individual in the team can also learn towards their self-development (Scarnati, 2001; Campion et al. 1993; Johnson, Heimann, & O’Neill, 2000; Smith, 1996).

**Adherence to Team Process and Performance**

There are several factors which drive a team towards a successful team process and performance. Team members should be encouraged to make decisions leading towards an effective work process. The decisions made by a team must ensure a drive for feasible solutions that will benefit the team (Bracklin & Williams, 2001). With respect to problem solving, team members should focus on the process, develop strategies, drive innovation and creativity ensure feasible solutions (Cannon-Bowers et al. 1993; Valdez & Kleiner, 1996; Wageman, 1997). According to (Wageman, 1997) team members should also seek best practices from cross-functional teams and teams in different workplaces to ensure teamwork
effectiveness. These factors should encourage group participants’ consensus towards successful process and performance within the team.

Conclusion and Future Work

Our study suggests that there is a gap in engineering education research on the use of effective teamwork models and also a lack of consensus among engineering instructors on how to effectively teach teamwork skills to engineering students. After conducting a systematic review of the literature, we were able to find 11 attributes that make teamwork effective. These attributes will highlight the importance of teamwork effectiveness among engineering instructors and also help as a guide when teaching teamwork to engineering students. The attributes should not be considered in isolation from one another and each attribute should be holistically considered when trying to establish effective teamwork practices within a team. Also, we should not consider any hierarchy among the teamwork attributes. In future, we would want to explore the balance of the teamwork attributes in different levels of engineering students who are involved in different task involving teamwork. We would like to understand which attributes are considered more important based on the unique engineering team experiences. It would also be interesting to determine whether any of the teamwork attributes are more or less influential for a given team. Therefore, the context and purpose of the teamwork is important when considering these attributes as all of them might not appear in different teams.

The 11 key attributes can be used to develop and sustain effective teamwork. We should be aware that the attributes are an initial set of considerations with the understanding that there may be a need for further exploration to identify how the attributes can be developed together as a teamwork model. This foundational exploration will help researchers currently engaged in teamwork enhancement and may lead to the identification of areas requiring additional research.

We plan to look into existing instruments used for measuring teamwork effectiveness, compare them and find out the gaps in measuring the attributes. As a future work, we plan to develop a survey where we can measure and monitor the teamwork attributes of different teams in order to enhance teamwork effectiveness. In addition, we plan to make an interview protocol consistent to our conceptual framework and implement it in different teams at the institution. The implementation phase will include observations on teamwork processes and classify different kinds of teams in order validate on how they adapt with our proposed framework.

References


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Assessing the grit and mindset of incoming engineering students with an emphasis on gender

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Abstract: Engineering programs can be very demanding, particularly in the first years where students encounter new forms of highly challenging coursework. To better prepare and support students, educators must acknowledge non-academic factors, such as the role of self-beliefs and personal attributes. Education research suggests that students are more likely to give up and disengage from their studies when they lack grit or assume a fixed mindset. Previous studies suggest that female students are generally grittier but less confident when compared to male students. This paper presents the initial work of an ongoing study to explore self-confidence and motivations to study engineering of first year engineering students experiencing a new multi-disciplinary curriculum. A dataset collected via an online survey at the start of the academic year with 102 students was analysed. Gender comparisons were undertaken to explore the association between self-confidence and motivations with grit and mindsets.

Introduction
The world of engineering is constantly evolving, requiring engineers to be able to maintain focus on long-term complex problems, and be able deal with setbacks. To better prepare students for real-world engineering problems, higher education institutions must acknowledge academic as well as psychological demands engineering challenges. Research on the role of self-beliefs and personal attributes, that include grit and mindset, is essential to understand their potential impact on academic performance and personal achievements (Burtner, 2005; Hsieh, Sullivan, Sass, & Guerra, 2012; Shechtman, DeBarger, Domsife, Rosier, & Yarnall, 2013). This line of research can ultimately contribute to the design of evidence-based interventions to better support students.

Engineering programs are often hard, demanding high levels of self-discipline and commitment to face and overcome a variety of academic challenges (Pierrakos, 2017), particularly in the first years where students encounter challenging new types of coursework and modes of thinking. Having ‘grit’ can help students face and overcome tough challenges. Grit has been defined as perseverance and passion for long-term goals (Duckworth, Peterson, Matthews, & Kelly, 2007). Research on grit and its relationship to persistence and retention in engineering education is relatively recent, with most of the publications in the area being in conference proceedings and reporting preliminary data (Direito, Chance, &
Manish, under review). However, studies suggest that female students are, on average, grittier than male (e.g. Bottomley, 2015; Choi & Loui, 2015).

Research in engineering has linked dropout rates with self-perception, indicating students with fixed mindsets are more likely to give up when facing new challenges (Heyman, Martyna, & Bhatia, 2002). Extensive research by Dweck (1999, 2017) has indicated students with a fixed mindset believe intelligence is an innate and fixed trait. In contrast, students with a growth mindset believe intelligence can be improved with effort and drive; this second group of students is less likely to disengage when confronted with difficult tasks.

Research on grit and mindsets is particularly relevant to understanding experiences of students considered to be non-traditional, and building knowledge in this realm is essential to supporting engineering students who have diverse needs and diverse preparatory experiences. For example, a relatively recent study has reported that grit levels were positively related to black males’ grades within one predominantly white institution (e.g. Strayhorn, 2014). Studies with engineering students indicated that their beliefs about intelligence were correlated with active learning strategies (e.g. Stump, Husman, & Corby, 2014), supporting the idea that developing interventions to develop growth mindsets can provide valuable support and possibly retain students in engineering (Campbell, Craig, & Collier-Reed, 2019).

In 2014, the University College London (UCL) Faculty of Engineering Sciences implemented a multi-disciplinary review of their engineering education curriculum – the Integrated Engineering Programme – where students, from the very beginning of their degree, engage with the practical application of engineering and skills needed to undertake engineering projects effectively (Mitchell, Nyamapfene, Roach, & Tilley, 2019). In the early stages, in order to study the student experiences in navigating this programme, data were collected through focus groups and online surveys. At that time, however, no data on psychological factors were included. Starting in the academic year of 2018/19, quantitative data were collected through an online survey to provide ideas for a longitudinal study of such factors.

**Method**

The assessment of students’ psychological factors through surveys, using psychometric instruments, and is a common practice in engineering education research (e.g. Kim et al, 2018; Scheidt et al., 2018), as it helps to identify relationships between variables in the students’ profiles that support or hinder their academic success. This paper describes the initial work of an ongoing longitudinal study to explore the expectations and motivations of engineering students and the impact of grit and mindset on their learning experiences. This study follows an explanatory mixed methods design (Borrego, Douglas, & Amelink, 2009), with two phases: The quantitative data collected via an online survey (phase 1), will be analysed and findings will be used to inform the design of new qualitative interview questions (phase 2). Data collected in the first phase of will also help identify potential interview participants.

**Participants**

An initial sample of 103 first-year engineering students responded to the 2018/19 survey, 32% (N=33) identified as female (F), and 67% (N=69) identified as male (M). Only one student preferred not to answer and was excluded from binary gender comparisons. The breakdown by domicile status was 25.2% United Kingdom, 21.4% European countries, and 52.4% non-European countries. Participants were primarily based in Computer Science (30.1%) or Engineering, including Chemical (20.4%), Mechanical (19.4%), and Electronic and Electrical (17.5%). More than one-third of the students identified as Asian (38.8%) and almost a quarter identified as White (23.3%). The vast majority of the students were second-generation students (79.6%), meaning that they were not first in the family studying in Higher Education.
Survey and instruments

During the first weeks of the 2018/19 academic year, incoming engineering students completed an online survey comprising statements about their self-confidence regarding a set of specific engineering skills and motivations to study engineering. Survey statements regarding self-confidence were adapted from previous surveys developed by the IEP team, where students answered the question ‘How confident are you in your current skills and ability to do the following?’ using a 5-point-Likert scale (1 = not at all confident; 5 = very confident). In the new survey, statements exploring motivations to study engineering were adapted from the Academic Pathways of People Learning Engineering Survey (APPLES, by Sheppard et al., 2010). The APPLES survey defined motivations according to different categories: financial (F), parental influence (PI), social good (SG), mentor influence (MI), intrinsic-psychological (IP), and intrinsic-behavioural (IB). Students indicated the extent to which each reason to study applied to them using a 5-point Likert scale (1 = not a reason; 5 = major reason). A list of possibilities was presented following the explanation, ‘We are interested in knowing why you are studying engineering’.

Participants were also asked to respond to two psychometric instruments—the Short Grit Scale, and Implicit Theories of Intelligence Scale—both of which are described below.

**Short Grit Scale**

The Short Grit Scale (Grit-S), is an abbreviated version (Duckworth & Quinn, 2009) of a self-report instrument originally developed measure the two dimensions of grit (Duckworth, Peterson, Matthews, & Kelly, 2007). These two dimensions are: (1) passion or, more specifically, ‘consistency of interest’ and (2) perseverance for long-term goals, which is also known as ‘perseverance of effort’. Passion is defined as the ability to hold the same interests over time, whereas perseverance is defined as the ability to work consistently towards a defined goal. The short version on the instrument comprises 8 items (4 items for each dimension, passion and perseverance) to be answered according to a 5-point Likert scale, ranging from 1 ‘not at all like me’ to 5 ‘very much like me’. One overall grit score is calculated for each person by totalling the sum of the scores and then dividing it by the total number of items. A grit score of 5 is, therefore, the maximum value of the instrument and it would describe a very gritty person. On the opposite end, a grit score of 1 is the minimum value a person could rate and it would describe someone who lacks grit.

**Implicit Theories of Intelligence Scale**

This study also seeks to understand mindset, and thus investigates the theories of intelligence that students hold. Students’ ideas about intelligence were measured using the 8-item Implicit Theories of Intelligence Scale (Dweck, 1999). Of the 8 items, 4 items correspond to growth mindset (incremental theory of intelligence) and 4 correspond to fixed mindset (entity theory). When completing this survey, participants were instructed to indicate the extent to which they agreed or disagreed with each of the statements using a 6-point Likert scale (1 ‘strongly agree’, 2 ‘agree’, 3 ‘mostly agree’, 4 ‘mostly disagree’, 5 ‘disagree’, 6 ‘strongly disagree’). Participants’ scores for the ‘growth items’ were reversed (e.g. 1 becomes a 6, 2 becomes a 5, etc.), so that strongly disagreeing with a ‘fixed item’ was similar to strongly agreeing with a ‘growth item’. The score was then calculated by dividing the sum of individual scores by the total number of items. Using this system, scores ranging between 1 and 3 suggest the individual has a fixed mindset, whereas scores between 4 and 6 suggest growth mindset. Scores in between 3 and 4 represent an unclear positioning.

**Procedure**

The current research project was evaluated and approved by UCL Ethics Committee because personal data, such as students’ demographics, were to be processed. Following good practices of General Data Protection Regulation (GDPR), all potential participants were given an information sheet about the project and data handling.
The dataset was analysed using SPSS 25. For reporting purposes, the level for statistical significance was set at 0.05. Appropriate non-parametric tests were selected because the distribution of most of variables under analysis (items for self-confidence, motivation to study, grit and mindsets) had not passed the tests for normality. Since they did not follow a standard normal distribution, the data were analysed using Mann-Whitney non-parametric tests to assess whether the medians of the two independent groups (female and male) differed significantly from each other. Effect sizes for Mann-Whitney tests were calculated according to Fritz, Morris and Richler (2012) and interpreted using Cohen’s rule of thumb (1988) with 0.1 tagged as a small effect, 0.3 as medium, and 0.5 as large. Spearman correlation coefficients were also analysed—to identify the statistical dependence between the rankings of two variables (e.g. level of confidence in skill and level of grit).

In addition to describing the overall findings for the total sample of students, the analyses presented in this paper identify correlations between students’ gender and: self-confidence in a set of engineering related skills; motivations to study engineering; grit; and mindset.

**Results**

Participants were asked to rate their level of confidence and ability to perform a set of 15 skills using a 5-point Likert scale (1 = not at all confident; 5 = very confident) (Table 1). As a group, female students rated themselves significantly lower with regard to “solving ill-defined real-world problems” (r=.28) and “applying technical engineering knowledge to real problems” (r=.31) than male students rated themselves.

Although the group of women also rated themselves lower in “solving technical engineering problems and performing calculations” and “working with engineers from other disciplines and supporting each other to reach project goals” than men did, these confidence differences did not reach statistical significance at the prescribed level. Likewise, no significant gender differences were found in regard to the motivations for studying engineering (Table 2). The most relevant of the motivations were intrinsic, including motivations related to social good. Nonetheless, male students were more likely to rate higher in statements concerning intrinsic motivation (e.g. “I feel good when I am doing engineering”, “I think engineering is fun”), whereas female students were more likely to rate higher in statements related to the social good of engineering (e.g. “Engineering skills can be used for the good of society”).

The analyses of students’ scores on the psychometric instruments revealed no statistical significant gender differences, although female students were more likely to have lower levels of grit and were more likely to consider intelligence as being incremental (Table 3).

Data were then analysed to explore the relationship between students’ self-confidence and motivations to study engineering with regard to both grit and mindset.

For the female group as well as the male group, moderate positive correlations were found between grit-perseverance and “working effectively within a diverse and multidisciplinary team of people” (female: r=.443, p=.010; male: r=.380, p=.001) as well as “presenting ideas to other in a clear and engaging way” (female: r=.374, p=.032; male: r=.390, p=.001). These findings suggest that students’ confidence in this type of social and communication may be associated with their reported subjective ability to work persistently.

In addition to this, and just for male students, small positive correlations were found between grit-perseverance and both “applying technical engineering knowledge to real problems” (r=.239, p =.048) and “thinking and working in accordance to ethical principles” (r=.245, p=.042). Also, for male students, a small positive correlation was found between mindset and “interacting with clients to provide a technical solution that suits their needs, solves their problems and helps them reach their goals” (r=.282, p=.019).
### Table 1. Differences in skills confidence by gender

<table>
<thead>
<tr>
<th>Survey item</th>
<th>gender</th>
<th>M</th>
<th>SD</th>
<th>Mdn</th>
<th>U</th>
<th>p</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>*Solving ill-defined real-world problems</td>
<td>F</td>
<td>2.55</td>
<td>0.711</td>
<td>3.00</td>
<td>1,511.0</td>
<td>.005</td>
<td>.28</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>3.07</td>
<td>0.929</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Developing innovative and creative engineering ideas</td>
<td>F</td>
<td>3.15</td>
<td>1.064</td>
<td>3.00</td>
<td>1,170.5</td>
<td>.810</td>
<td>.02</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>3.19</td>
<td>0.928</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working effectively within a diverse and multi-disciplinary team of people</td>
<td>F</td>
<td>3.85</td>
<td>0.870</td>
<td>4.00</td>
<td>1,026.0</td>
<td>.397</td>
<td>-.08</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>3.70</td>
<td>0.960</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solving technical engineering problems and performing calculations</td>
<td>F</td>
<td>3.24</td>
<td>0.902</td>
<td>3.00</td>
<td>1,321.0</td>
<td>.172</td>
<td>.14</td>
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<tr>
<td></td>
<td>M</td>
<td>3.55</td>
<td>0.993</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Designing and building an effective prototype</td>
<td>F</td>
<td>2.79</td>
<td>0.992</td>
<td>3.00</td>
<td>1,246.0</td>
<td>.419</td>
<td>.08</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>2.97</td>
<td>0.907</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Making intelligent estimates of size, scale and quantity using engineering knowledge</td>
<td>F</td>
<td>2.88</td>
<td>0.927</td>
<td>3.00</td>
<td>1,309.0</td>
<td>.203</td>
<td>.13</td>
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<tr>
<td></td>
<td>M</td>
<td>3.20</td>
<td>1.051</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>*Applying technical engineering knowledge to real problems</td>
<td>F</td>
<td>2.85</td>
<td>0.834</td>
<td>3.00</td>
<td>1,549</td>
<td>.002</td>
<td>.31</td>
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<tr>
<td></td>
<td>M</td>
<td>3.45</td>
<td>0.867</td>
<td>3.00</td>
<td></td>
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<td>Working in a professional real-world engineering setting</td>
<td>F</td>
<td>2.61</td>
<td>0.899</td>
<td>3.00</td>
<td>1,355.0</td>
<td>.106</td>
<td>.16</td>
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<tr>
<td></td>
<td>M</td>
<td>2.99</td>
<td>1.091</td>
<td>3.00</td>
<td></td>
<td></td>
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<tr>
<td>Presenting ideas to others in a clear and engaging way</td>
<td>F</td>
<td>3.30</td>
<td>0.918</td>
<td>3.00</td>
<td>1,192.0</td>
<td>.693</td>
<td>.04</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>3.38</td>
<td>1.214</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interacting with clients to provide a technical solution that suits their needs, solves their problem and help them reach their goals</td>
<td>F</td>
<td>2.97</td>
<td>1.104</td>
<td>3.00</td>
<td>1,311.0</td>
<td>.199</td>
<td>.13</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>3.23</td>
<td>1.017</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working with engineers from other disciplines and supporting each other to reach project goals</td>
<td>F</td>
<td>3.30</td>
<td>0.984</td>
<td>3.00</td>
<td>1,263.0</td>
<td>.349</td>
<td>.09</td>
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<tr>
<td></td>
<td>M</td>
<td>3.51</td>
<td>0.949</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Writing technical reports</td>
<td>F</td>
<td>2.85</td>
<td>1.093</td>
<td>3.00</td>
<td>994.0</td>
<td>.280</td>
<td>-.11</td>
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<tr>
<td></td>
<td>M</td>
<td>2.68</td>
<td>0.931</td>
<td>3.00</td>
<td></td>
<td></td>
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<tr>
<td>Developing sustainable solutions on behalf of a company or for clients</td>
<td>F</td>
<td>2.67</td>
<td>0.924</td>
<td>3.00</td>
<td>1,325.0</td>
<td>.155</td>
<td>.14</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>2.93</td>
<td>0.846</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thinking and working in accordance to ethical principles</td>
<td>F</td>
<td>3.58</td>
<td>0.936</td>
<td>4.00</td>
<td>1,165.5</td>
<td>.838</td>
<td>.02</td>
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<tr>
<td></td>
<td>M</td>
<td>3.59</td>
<td>1.062</td>
<td>4.00</td>
<td></td>
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<tr>
<td>Considering the social impact of engineering decisions and products</td>
<td>F</td>
<td>3.48</td>
<td>0.939</td>
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<td>1,097.0</td>
<td>.753</td>
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<td></td>
<td>M</td>
<td>3.43</td>
<td>0.977</td>
<td>4.00</td>
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</tr>
</tbody>
</table>

Note: Statistical significance identified with *
Table 2. Motivations to study by gender

<table>
<thead>
<tr>
<th>Survey item (Category)</th>
<th>Gender</th>
<th>M</th>
<th>SD</th>
<th>Mdn</th>
<th>U</th>
<th>p</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology pays an important role in solving society's problems (SG)</td>
<td>F</td>
<td>3.82</td>
<td>0.950</td>
<td>4.00</td>
<td>1,351.0</td>
<td>.105</td>
<td>.16</td>
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<tr>
<td></td>
<td>M</td>
<td>4.12</td>
<td>0.883</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineers make more money than most other professionals (F)</td>
<td>F</td>
<td>2.88</td>
<td>1.166</td>
<td>3.00</td>
<td>1,157.5</td>
<td>.889</td>
<td>.01</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>2.93</td>
<td>1.264</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>My parent(s) would disapprove if I chose a major other than engineering (PI)</td>
<td>F</td>
<td>1.39</td>
<td>0.899</td>
<td>1.00</td>
<td>1,237.5</td>
<td>.377</td>
<td>.09</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>1.61</td>
<td>1.114</td>
<td>1.00</td>
<td></td>
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</tr>
<tr>
<td>Engineers have contributed greatly to fixing problems in the world (SG)</td>
<td>F</td>
<td>4.00</td>
<td>0.791</td>
<td>4.00</td>
<td>1,143.5</td>
<td>.969</td>
<td>.00</td>
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<tr>
<td></td>
<td>M</td>
<td>4.00</td>
<td>0.840</td>
<td>4.00</td>
<td></td>
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<td></td>
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<tr>
<td>Engineers are well paid (F)</td>
<td>F</td>
<td>3.15</td>
<td>1.004</td>
<td>3.00</td>
<td>1,076.5</td>
<td>.645</td>
<td>-.05</td>
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<td></td>
<td>M</td>
<td>3.03</td>
<td>1.124</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>My parent(s) want me to be an engineer (PI)</td>
<td>F</td>
<td>1.48</td>
<td>0.939</td>
<td>1.00</td>
<td>1,201.5</td>
<td>.586</td>
<td>.05</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>1.68</td>
<td>1.157</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>An engineer degree will guarantee me a job when I graduate (F)</td>
<td>F</td>
<td>3.12</td>
<td>1.053</td>
<td>3.00</td>
<td>988.0</td>
<td>.267</td>
<td>-.11</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>2.84</td>
<td>1.244</td>
<td>3.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A faculty member has encouraged/inspired me to study engineering (MI)</td>
<td>F</td>
<td>2.30</td>
<td>1.334</td>
<td>2.00</td>
<td>957.0</td>
<td>.168</td>
<td>-.14</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>1.96</td>
<td>1.230</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A non-university affiliated mentor has encouraged and/or inspired me to study engineering (MI)</td>
<td>F</td>
<td>1.97</td>
<td>1.075</td>
<td>2.00</td>
<td>1,170.5</td>
<td>.809</td>
<td>.02</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>2.12</td>
<td>1.290</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A mentor has introduced me to people and opportunities in engineering (MI)</td>
<td>F</td>
<td>1.91</td>
<td>1.128</td>
<td>1.00</td>
<td>1,101.5</td>
<td>.773</td>
<td>-.03</td>
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<td></td>
<td>M</td>
<td>1.84</td>
<td>1.106</td>
<td>1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I feel good when I am doing engineering (IP)</td>
<td>F</td>
<td>3.27</td>
<td>1.232</td>
<td>3.00</td>
<td>1,323.0</td>
<td>.165</td>
<td>.14</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>3.59</td>
<td>1.089</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I like to build stuff (IB)</td>
<td>F</td>
<td>3.55</td>
<td>1.348</td>
<td>4.00</td>
<td>1,293.5</td>
<td>.248</td>
<td>.11</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>3.88</td>
<td>1.145</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I think engineering is fun (IP)</td>
<td>F</td>
<td>3.73</td>
<td>1.126</td>
<td>4.00</td>
<td>1,342.5</td>
<td>.124</td>
<td>.15</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>4.07</td>
<td>1.005</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering skills can be used for the good of society (SG)</td>
<td>F</td>
<td>4.36</td>
<td>0.742</td>
<td>5.00</td>
<td>915.5</td>
<td>.089</td>
<td>-.17</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>3.99</td>
<td>1.022</td>
<td>4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I think engineering is interesting (IP)</td>
<td>F</td>
<td>4.12</td>
<td>0.992</td>
<td>4.00</td>
<td>1,253.0</td>
<td>.373</td>
<td>.09</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>4.29</td>
<td>0.909</td>
<td>5.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I like to figure out how things work (IB)</td>
<td>F</td>
<td>4.33</td>
<td>0.890</td>
<td>5.00</td>
<td>1,250.5</td>
<td>.349</td>
<td>.09</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>4.49</td>
<td>0.816</td>
<td>5.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>A mentor has supported my decision to major in engineering (MI)</td>
<td>F</td>
<td>2.18</td>
<td>1.261</td>
<td>2.00</td>
<td>1,035.0</td>
<td>.431</td>
<td>-.08</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>2.01</td>
<td>1.254</td>
<td>2.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

When exploring students’ motivations to study engineering, moderate negative correlations were found among female students between grit and “engineers make more money than most of other professionals” ($r =-.484, p =.004$) and “engineers are well paid” ($r =-.544, p =.001$), suggesting that women with lower grit levels were more likely to have financial motivations to study engineering.

For male students, positive correlations were found between the grit and three specific intrinsic psychological motivations: “I think engineering is interesting” ($r =.403, p =.001$), “I feel good when doing engineering” ($r =.238, p =.049$), and “I think engineering is fun” ($r =.377, p =.001$). Curiously, the reason “I think engineering is fun” has a stronger correlation with the perseverance trait (respectively, $r =.381, p =.001$; $r =.397, p =.001$) than with the passion trait (respectively, $r =.241, p =.046$, $r =.251, p =.037$). A small positive correlation was identified.
between grit-perseverance and the intrinsic behavioural reason “I like to figure out how things work” \( r = .287, p = .017 \).

<table>
<thead>
<tr>
<th>Instrument</th>
<th>Gender</th>
<th>M</th>
<th>SD</th>
<th>Mdn</th>
<th>U</th>
<th>P</th>
<th>r</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grit</td>
<td>F</td>
<td>3.35</td>
<td>0.621</td>
<td>3.250</td>
<td>1,258.0</td>
<td>.391</td>
<td>.08</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>3.45</td>
<td>0.582</td>
<td>3.500</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grit-passion</td>
<td>F</td>
<td>3.23</td>
<td>0.754</td>
<td>3.250</td>
<td>1,122.5</td>
<td>.908</td>
<td>-.01</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>3.23</td>
<td>0.756</td>
<td>3.250</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grit-perseverance</td>
<td>F</td>
<td>3.48</td>
<td>0.746</td>
<td>3.500</td>
<td>1,326.5</td>
<td>.176</td>
<td>.13</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>3.68</td>
<td>0.663</td>
<td>3.750</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mindset/Intelligence</td>
<td>F</td>
<td>4.02</td>
<td>0.720</td>
<td>4.000</td>
<td>1,066.0</td>
<td>.604</td>
<td>-.05</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>3.87</td>
<td>1.190</td>
<td>3.875</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For female students, a moderate negative correlation was found between mindset and “my parents would disapprove if I chose a major other than engineering” \( r = -.407, p = .019 \), suggesting that this parental influence motivation was more likely to be relevant for women with a fixed theory of intellectual ability.

On the other hand, among male students, a small negative correlation was identified between grit and the same statement, “my parents would disapprove if I chose a major other than engineering” \( r = -.239, p = .048 \), suggesting this parental influence was more relevant for male students with lower levels of grit. In addition, for male students, a small negative correlation was found between grit-perseverance and “my parents want me to be an engineer” \( r = -.255, p = .034 \), suggesting that those doing engineering for their parents might persevere less. Also, for the male group, a small positive correlation was evident between mindset and “a non-university affiliated mentor has encouraged and/or inspired me to study engineering” \( r = .293, p = .014 \), linking growth mindset to those with encouraging mentors.

**Discussion**

This study aims to expand on the assessment of student perspectives and characteristics that could influence learning approaches and success. Initial quantitative data analyses, reported here, corroborate previous findings made during assessment of first-year IEP engineering students’ self-confidence; those early findings suggested UCL’s female IEP students were more likely to feel less confidence in their technical skills (Direito, Tilley, & Mitchell, 2018). However, none of these findings are yet clear enough to generalize or make robust interpretations. Further research over time, expanded to include qualitative data collection, will help the team better understand the role psychological factors play in students’ confidence during their engineering studies, and support the assessment and refinement of learning environments in the IEP and engineering education more generally.

**References**


Direito, I., Chance, S. M., & Malik, M. (under review). The study of grit in engineering education research: A systematic literature review.


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Exploring the Discursive Construction of Ethics in an Introductory Engineering Course

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Abstract: Engineering education must prepare students to assume professional responsibility for the societal impacts of technology. However, previous research suggests that most engineering students do not receive adequate training for assuming this responsibility; in this paper, I explore why this may be so. Using a discourse analytic approach on ethnographic field notes, lecture recordings, interview data, and course documents, I explore how ethics and ethical reflection are articulated in an introductory engineering course in Sweden. The results illustrate how ethics is articulated as “something other” than the core subject area, of inferior quality, and as something that is not very important and that cannot and does not need to be learned or developed in engineering education.

Introduction
There is today a broad international consensus that engineering education must prepare students to assume professional responsibility for the societal impact of technology (Buckridge, 2011; Wang, Zhang, & Zhu, 2015). Assuming this responsibility requires the ability to take “well-reasoned ethical decisions” in engineering practice (Beever & Brightman, 2016, p. 275). However, a large body of research suggests that there is a lack of education in engineering ethics (Colby & Sullivan, 2008). For example, many practicing engineers experience that their education did not adequately prepare them to deal with ethical issues in the profession (McGinn, 2003). Shuman et al. (2004) found low levels of ethical reasoning among engineering students and no significant difference between freshmen and senior students, which suggests that students’ ethical reasoning ability did not improve during undergraduate engineering education. Similarly, Finelli et al. (2012) suggested that engineering students’ level of ethical reasoning may be lower than that of students in other majors. Stappenbelt (2013) found that almost one-third of Australian engineering students do not believe that practicing engineers act ethically, nor that it is realistic to expect this behavior. Engineering students have also been found to be less committed to social action than students in other majors (Sax, 2000) and their interest in understanding the consequences of technology appears to decrease over the course of their undergraduate studies (Cech, 2014). Cech explains the findings from her study by suggesting that engineering education and practice is characterized by a pervasive “culture of disengagement”. In this culture, non-technical concerns are often constructed as less important than purely technical concerns and engineering students are taught “to distance themselves from public welfare considerations [such as ethics] in the process of becoming engineers” (Cech, 2014, p. 46; see also Allie & al., 2009; Downey & Lucena, 1997).

In this paper, I report on results from an ethnographic study that aimed to explore how this culture of disengagement is discursively constructed and perpetuated in engineering education. More specifically, I report on results from a discourse analysis that aimed to explore how the concepts of ethics and ethical reflection are discursively constructed in an introductory engineering course in Sweden.
Theoretical framework

Ethics in engineering education

In the engineering education literature, the concept of ethics has been described as consisting of three dimensions: 1. “ordinary morality”, which refers to standards of conduct that apply to everybody, such as “don’t kill”; 2. “moral theory”, i.e. a philosophical discipline; and 3. professional ethics that only apply to members of certain groups (e.g. engineering ethics, which apply to engineers “and no one else”) (Davis, 2006). Davis argues that engineering education should focus on professional ethics, but he admits that “professional ethics differs from ordinary morality, when it does differ, only in demanding more ("a higher standard")” (2006, p. 719). Since this paper presents an exploratory study, I have chosen to define ethics as a broad concept that includes all three of Davis’ dimensions of ethics.

Based on a systematic review of the literature on ethics interventions in US engineering education, Hess and Fore (2018) identified three types of learning goals for ethical development: ethical sensitivity/awareness, ethical judgment/decision-making, and ethical commitment/confidence. In this paper, I use the term ethical reflection to denote an activity that foregrounds ethical judgment/decision-making, but implicitly also draws on ethical sensitivity/awareness and ethical commitment/confidence. While some scholars argue that ethical commitment cannot and should not be taught in engineering education (e.g. Abaté, 2011), I argue that it is neither desirable nor possible to separate the three types of learning goals from each other, since it is not possible to engage in ethical judgment without first becoming aware of ethical concerns and committing oneself to paying attention to these concerns. Drawing on Cech’s description of the culture of disengagement in engineering education, I argue that ethical awareness and commitment are, at least to some degree, learned through socialization processes in engineering education:

“Aspiring engineers are introduced to their professional roles and responsibilities through the process of professional socialization. Through classes, internships, design projects, and friendships, students are transformed from laypersons into engineers; they are expected to adopt the profession’s epistemologies, values, and norms; identify with particular symbols; and learn to project a confident, capable image of expertise.” (Cech, 2014, p. 49)

In other words: by adopting values and norms that are articulated in engineering education (for example related to ethics), students learn to view certain practices and concerns as important for engineering and others as tangential.

Discourse theory

The research presented in this paper is based on a social constructionist perspective and, more specifically, on discourse theory (Laclau & Mouffe, 1985). Discourse theory is one of a range of approaches to the analysis of discourse. Jørgenssen and Phillips (2002, p. 1) define discourse as “a particular way of talking about and understanding the world (or an aspect of the world).” They further state that discourse analysis, like all other social constructionist approaches to research, is based on a relativist epistemology according to which we do not have direct access to reality. Rather,

“our access to reality is always through language. With language, we create representations of reality that are never mere reflections of a pre-existing reality but contribute to constructing reality. That does not mean that reality itself does not exist. Meanings and representations are real. Physical objects also exist, but they only gain meaning through discourse.” (ibid, pp.8-9)

In discourse theory, the process through which representations of reality are constructed is called articulation, which is described as “any practice establishing a relation among elements such that their identity is modified as a result of the articulatory practice” (Laclau &
Mouffe, 1985, p. 105). In other words, articulation is the process through which meanings are temporarily fixed to give priority to certain discourses (rather than others). Articulation structures discourses around central elements, so-called nodal points, that are articulated through relations with other elements (ibid.). For example, an important nodal point in this paper is “ethics” and the analysis (see below) focuses on identifying elements that are related to ethics. Articulation is always contingent on specific contexts and can, therefore, be changed. The concept of disarticulation is often described as the process of undoing an articulation and thus changing the meaning of a nodal point (Clarke, 2015). In this paper, however, I use the term to denote the process of articulating elements as different from other elements, i.e. the process of constructing opposition among elements. Articulation and disarticulation can occur through several steps, creating chains of equivalence (figure 1). Finally, while some elements are clearly articulated in certain contexts, others remain “vague, highly variable, unspecifiable” and they may “mean different things to different people”. In discourse theory, these elements are called floating signifiers (Chandler, n.d.; see also Mehlman, 1972).

Figure 1. A nodal point (dark blue) is articulated (blue, continuous lines) in relation to elements (blue) B and C via a chain of equivalence, and simultaneously disarticulated (red, dashed line) in relation to element A.

Methods

Research context

The study context is a five-year engineering program in Sweden¹. The program combines undergraduate and graduate studies; students who finish the program are awarded a Master of Science degree. Every year, 60 students are accepted to start on the program. Female students are in a clear minority: typically, less than five of the incoming students are women. The success rate for the program is low and it is common that less than half of the incoming cohort completes their studies. For those students who do complete the program, however, job prospects are generally very good.

The research presented in this paper focuses on the first course in the program. It is a broad introductory course that covers topics such as group and project work, design methodology, study techniques, oral presentations, repetition of basic mathematics skills, outlooks on the future profession, and ethics. The course runs over 4.5 weeks and is given on a full-time basis. The course includes a variety of lectures, guest lectures, and seminars. The course also includes a group project during which students develop a computer game.

According to the course description, the ethics teaching in the course aims to develop the students’ ability to discuss their future professional roles, including moral/ethical concerns that may arise in the professional context. At the time of data collection, the ethics teaching consisted of several different activities. First, towards the beginning of the course, the students had a lecture on ethics in which the concept of professional ethics and two professional codes of ethics were introduced. During this lecture, students also discussed several fictive ethics cases (e.g. related to automatization and intellectual property rights) in small groups and from different perspectives (e.g. as an employee or customer). At the end of the lecture, the students were given a task description for an individual reflective essay that was due at the end of the course. For the essay, each student had to identify a specific situation (an ethical dilemma) that they could expect to encounter in their later professional life. The students also had to apply at least one of the professional codes to the dilemma and

¹For the results presented in this paper, the specific type of engineering program is deemed to be insignificant; this information is therefore omitted to protect participants’ anonymity.
discuss how they would act if they were faced with this dilemma. Second, the teachers organized a company fair for all students in the program. During this fair, the first-year students were to talk to representatives from different companies and ask them about their experiences with ethical dilemmas in the profession. Third, the students had a guest lecture during which they discussed classical moral dilemmas (such as the trolley problem) and profession-specific dilemmas. In this lecture, the teacher used the polling software Mentimeter to allow students to anonymously state their opinions on the dilemmas. The teacher then asked the students to discuss and explain the results in plenum. Fourth, the students had a mandatory seminar during which they, among other topics, discussed the answers they had received from the company representatives about ethical dilemmas in the profession. Finally, at the end of the course, the students had to hand in their reflective essays and, three weeks later, the teacher who had graded the essays held a short feedback session and returned the essays.

Data collection

To collect data, I used an ethnographic approach (Atkinson & Hammersley, 2007), following the students to most of their lectures and seminars during the course. In some instances, I participated in group discussions or worked on mathematics problem sets together with the students, but I mostly focused on observing and producing jottings. Jottings are brief written notes that are taken during field observations and that later serve as a memory support for constructing detailed fieldnotes (Emerson, Fretz, & Shaw, 2011). To produce jottings, I used Melin’s system of stenography (Anon., n.d.), which allowed me to produce detailed notes, including shorter verbal quotes. I primarily focused on observing actions, e.g.: What did teachers and students talk about and how? How did they relate to each other? Did they express (dis)agreement on certain topics? What types of student behavior and expressions were praised or scolded? I also took notes on, for example, physical settings; how students and teachers positioned themselves and moved in these settings; how they were dressed; and my own actions, experiences, and reflections during the observations. As soon as possible after each observed activity (typically by the next day), I expanded the jottings into digital fieldnotes, thus producing a more detailed description and adding personal reflections and preliminary ideas for analysis and interpretation (Emerson et al., 2011). Data collection is still on-going and includes data not only from the introductory course, but also from two other first-year courses and student welcome activities. So far, the fieldnotes cover approximately 100h of observations. I have also audio-recorded selected lectures (~9h); conducted audio-recorded semi-structured interviews with five students and two teachers; and collected a wide range of documents, such as course and program descriptions, lecture slides and handouts, task descriptions, and student essays on ethical dilemmas (59). The research presented in this paper is based on an analysis of data relating to the introductory course, including fieldnotes and lecture-recordings, interviews with students and teachers, and selected lecture slides and task descriptions.

Data analysis

In ethnographic research, it is common to engage in preliminary data analysis in parallel with ongoing data collection. As researchers reflect on their observations and experiences in the field, they gradually develop a clearer focus for further data collection (Atkinson & Hammersley, 2007). In this study, the expansion of jottings into fieldnotes provided a valuable opportunity for continuous, preliminary data analysis (see also Emerson et al., 2011). Similarly, detailed verbatim transcription of audio-data provided an opportunity to develop a thorough understanding of the data and to note initial analytic ideas (Braun & Clarke, 2006). In addition, I discussed data excerpts and initial analytic ideas during several seminars and meetings with other researchers who work with discourse analysis and/or science and engineering education.

After the end of the introductory course, the analysis proceeded in six steps: First, I conducted an inductive thematic analysis in which I used open coding to produce a broad
understanding of interesting themes in the material (c.f. Braun & Clarke, 2006). This analysis was guided by a broad focus on how societal concerns are constructed in the course. This analysis resulted in 673 codes, organized under 19 parent codes (e.g. “emotions”, “teacher-student relationship”, “technology-society relationship”, and “importance”) and a total of 8236 coding instances where most data extracts were coded with several codes. As a result of this broad analysis, I identified ethics and ethical reflection as important nodal points to explore in further analysis. Second, I selected all codes (n=45) that could be related to ethics and ethical reflection (e.g. “ethical reflection”, “non-technical”, and “personal responsibility”) and retrieved all data extracts that were coded with these codes (n=735, including duplicates, i.e. segments that were coded with several of the relevant codes). The retrieved segments constituted the data set for further analysis. Third, I conducted a thematic analysis on the new data set. This analysis was theoretically informed by concepts from discourse theory (e.g. articulation, floating signifier) and from my previous research on complex sustainability problems in engineering education (Lönngren, 2017). This analysis resulted in 87 codes, organized under 19 parent codes (e.g. “is rendered important”, “floating signifier”, “is excluded from core subject area”) and a total of 880 coding instances. Fourth, I identified ethics and ethical reflection as important nodal points and selected all data excerpts (n=169) in which these nodal points were (dis)articulated in relation to other elements. This selection constituted the data set for further analysis. Fifth, I printed the new data set and color-coded nodal points, elements, and linguistic features that constructed linkages (e.g. “x is also y”, “and”) or oppositions (e.g. “x is not y”, “but”) among elements. Sixth, I drew a mind map to visualize all identified nodal points, linkages, and oppositions.

Results

Due to space limitations, it is not possible to describe all of the results from the analysis. Instead, I have chosen three articulatory themes that are particularly relevant for addressing the aim of the research, i.e. to explore how the concepts of ethics and ethical reflection are discursively constructed in an introductory engineering course in Sweden. These themes are ethics as “something other”, ethics and ethical reflection as unscientific, and quality of ethical reflection as a floating signifier. To illustrate these results, I use excerpts from transcripts and fieldnotes. For excerpts from fieldnotes, double citation marks are used; for verbal quotes within fieldnotes, single quotation marks are used. Italicized text indicates verbal stress and (…) indicates omissions from quotes. Square brackets indicate additions that are used to clarify the meaning of the quote and double round brackets are used to indicate non-verbal communication, such as laughter.

Ethics as “something other”

In several instances in the empirical material, ethics is articulated indirectly, i.e. through disarticulation. In these instances, ethics is described as “something other” than the core subject area of the engineering program. For example, one of the teachers says:

T²: Engineering programs are supposed to be broad and include different subjects. (…) There’s something that we call ‘general engineering courses’ and (…) you’re not allowed to take [those courses] at our department (…) You have to do something other. And I’d like to see even more of something other (laughs). Because I think that many [of the students] graduate with very, very, very deep knowledge of [subject area], very specialized knowledge. But I’d like to cut that down a little and instead get in a little more about the outside world (laughs). (Interview with a teacher)

The teacher provides a diverse set of examples of what could count as “something other”, for example business economics, law, philosophy, ethics, history of technology. Other examples that teachers mention during course activities include religion and foreign languages.

²In this study, I deemed it to be more important to protect the participants’ anonymity than to know who said what. I therefore use “T” for all teachers and “S” for all students.
Similarly, in one of the interviews, a student talks about religion, history, and social science as something other than engineering:

JL: What would you say is the biggest difference between high school and this [engineering] program?  
S: Well, that you *only* take courses in [subject area] and math. Like everything that has to do with [subject area]. Compared to the pre-engineering program I went to for high school. There you still had religion, history, social science, and things like that. So (…) it didn’t really feel like *engineering* because there was so much *other* stuff. (Interview with a student)

Students also describe that they experienced the ethics essay as something that does not clearly relate to the rest of the course. The essay was experienced as a “tick-box exercise”, something one just had to get done before going back to what is really relevant. In other words: the essay is disarticulated from the core content of the course and the program:

JL: What did you think about [the ethics essay] that you had to write?  
S: It felt like (…) it was just a tick-box exercise. Like it was just a check mark, a point on a list that you had to cross out. And then just like ‘oh look, our students [in subject area] need to be ethical!’ ‘Well, just throw *this* at them (…)!’  
JL: Right. Can you *pinpoint* what it was that made you feel like that?  
S: I think (…) it was quite *badly integrated* with the other assignments [in the course]. It really didn’t have *anything* to do with anything else [in the course]. (Interview with a student)

In summary, ethics is articulated as something that is not taught at the department (which can be anything from ethics to law, history, or foreign languages). Ethics is also explicitly disarticulated from the core content of the introductory course and the entire engineering program (figure 2).

**Ethics and ethical reflection as unscientific**

In several instances in the empirical material, *ethics* is articulated as “common sense” and disarticulated from scientific reasoning and writing. For example, on one of the presentation slides in the first lecture on ethics, professional ethics was defined as “formalized common sense”3. Similarly, in an interview, a student describes the professional codes of ethics as “mostly about common sense”. In another interview, a student suggests that one’s personal ethics may be more important than what is written in the professional codes:

JL: Do you think you’ll use them [the codes of ethics] again at some point?  
S: (…) No, I don’t think so. I mean, you’ll of course try to act ethically, but I think that you’ll mostly stick to your own ethics rather than what some other organization thinks you should do. There’s a lot of overlap [between the codes and one’s own ethics] (…), but I don’t think I’ll ask myself (…) ‘what do they think about *this*’? (Interview with student)

Thus, both students and teachers articulate ethics as common sense thinking that is based on personal values. Ethics is simultaneously disarticulated from resting on carefully developed principles that are worth learning and adhering to. In an academic context, where scientific knowledge is highly valued, articulating ethics as common sense thinking constructs ethics as having a lower status than the core content of the program. Similarly, in other data excerpts, *writing about ethical reflection* is constructed as having a lower status than writing about the core content of the program. This is due to a chain of equivalence that articulates 1. ethical reflection as something that is personal, 2. writing about personal topics as employing colloquial language, and 3. writing in colloquial language as inferior to scientific writing. I will start to illustrate the third step through an excerpt from an interview with the teacher who graded the ethics essays:

T: I’ve been *very forgiving* of their writing. I mean, (…) if I think they’ve used an *awful lot* of colloquial language, then I’ve commented on it. But I *haven’t* (…) corrected in their texts, like ‘*this* is wrong, and *this* is wrong, and *this* is wrong’. I’ve just said ‘this is worth thinking about’”. (Interview with a teacher)

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3 The Swedish expression used is “formaliserat bondförnuft”, which verbally translated would be “formalized farmers’ wisdom”.

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Expressions such as “an awful lot” and “this is wrong” clearly construct colloquial language as low-quality writing, even if the teacher does not fail students for having used colloquial language in their essays. Later in the interview, I returned to the topic of colloquial language to try to better understand how it is articulated:

JL: This issue with colloquial language (…), is that something you recognize from other tasks, lab reports or anything like that?
T: Yes, absolutely. And I have to say that was, uhm, I think it’s okay in this sort of task. And that’s what [teacher’s name] said as well, during his introduction [to the task], that it’s all right to write from an I-perspective and so on. Because this is a reflection, you’re supposed to think about your concerns, so it’s okay to talk about yourself and your [concerns]. But in general, I think people write worse and worse. Like they use more and more colloquial language and they don’t even notice that it’s colloquial. (…) There was one [student] who had [written] ‘våran’ och ‘vårat’⁴ and an awful lot of these kinds of expressions that, well, you don’t write like that in formal texts. (Interview with a teacher)

In this excerpt, the articulation of colloquial language (third step in the chain of equivalence) becomes even clearer when the teacher articulates “people write worse and worse” with “they use more and more colloquial language and they don’t even notice [it]” and “you don’t write like that in formal texts”. At the same time, the teacher (falsely?) articulates colloquial language with writing about personal topics from an I-perspective (second step in the chain of equivalence). She also articulates writing about personal topics with ethical reflection (first step in the chain of equivalence), saying that “it’s okay in this sort of task”. In other words, through three steps of articulation, ethical reflection is constructed as something that is of low quality and not appropriate “in formal texts”. This construction becomes even clearer through disarticulation of the ethics essay from scientific writing:

JL: Do they [the students] have anything in the program where they get instruction on how to write?
T: (…) There used to be, actually in this [course]. There used to be an activity on scientific writing and that kind of things. (…) But then this assignment [the ethics essay] turned out really weird because they [the students] thought they had to write it scientifically, so ((laughs)) they [the teachers] stopped doing that [activity]. (Interview with a teacher)

Scientific writing, in turn, is articulated as something that is advanced (only for graduate students) and worth teaching (through instruction and plenty of feedback). It is also articulated as being about the core subject area:

![Diagram of articulation](image)

Figure 2. Articulation of the nodal points (dark blue) “ethics and ethical reflection” and “core subject area” in relation to each other and other elements (blue). Continuous dark blue lines indicate articulation, dashed red lines indicate disarticulation.

⁴ “Våran” and “vårat” are colloquial forms of the Swedish pronouns “vår” and “värt”, both of which are translated to English as “our”.
Later, there is a course, at the graduate level, that we call ‘student conference in [subject area]’. In that course they [the students] write scientific papers, they pretend to write for a conference. And then they get a lot of feedback and then they get instruction on how to write. (Interview with a teacher)

Thus, the circle of articulation is closed: the core subject area is articulated as advanced and of high quality while anything that is not the core subject area (including ethics and ethical reflection) is articulated as of inferior quality and thus lower status. The results for the first two articulatory themes (ethics as “something other” and ethics and ethical reflection as unscientific) are summarized in figure 2.

Quality of ethical reflection as a floating signifier

Above, I have described how ethics is articulated broadly as anything that is not the core content of the course or the program. This broad articulation leaves the concept of ethics rather ill-defined, i.e. it remains a floating signifier that is open for different articulations. Without clearly articulating ethics, it is also difficult to articulate related nodes, such as the quality of ethical reflection, which therefore also remains a floating signifier. I observed this lack of articulation in the feedback session for the reflective essays.

The teacher opened the feedback session by stating: “I really enjoyed’ reading your texts. I think you’ve done a great job” (fieldnotes). The teacher then turned to talk about general concerns with how to write reports at university, stressing the importance of, for example, a “spacious layout” with a title page and a free-standing introduction, and correctly using references. The teacher particularly stressed the last point, saying: how to “write references, that’s something that you really have to look into before you write your next report” (fieldnotes). After a detailed treatment of how to write formal reports, the teacher concluded: “when it comes to reflecting, ‘there really isn’t anything that’s right or wrong.” Later, the teacher says that the students have not received a lot of individual feedback on their ethical reflection because ‘it’s hard to give exhaustive comments on something that is good’ (fieldnotes).

In other words, the teacher provided detailed quality criteria for formal aspects of the essay, but the quality of ethical reflection remained unarticulated. In fact, by stating that “there really isn’t anything that’s right or wrong” the teacher explicitly (though most certainly unconsciously) disarticulated ethical reflection from any type of quality criteria. Reflection on an ethical dilemma is “good” as soon as it is performed – in any form.

Unfortunately, this lack of articulation of the quality of ethical reflection seems to have contributed to articulating ethical reflection as something that is not very important and something that cannot and does not need to be learned or developed. For example, when the teacher asked the students to discuss their essays with each other, the students thought that “there wasn’t really a lot to talk about” because they had not “gotten any complaints (((laughs)) (...) on the essay” (interview with a student). All of the interviewed students expressed that they would have liked to get more individual feedback on their essays, but they also acknowledged that the teacher did not have enough time to do so. They also said that that was okay “because it [the reflective essay] wasn’t very important either”.

Discussion and Conclusion

In this paper, I have presented results from a study that aimed to explore how the concepts of ethics and ethical reflection are discursively constructed in an introductory engineering course in Sweden. Based on a discourse analysis of ethnographic data, I have argued that the core subject area of the engineering program is articulated as advanced and of high quality, while anything that is not the core subject area (including ethics and ethical reflection) is articulated as of inferior quality, lower status, not learnable, and not very important.

The results contribute to developing a better understanding of the processes through which a culture of disengagement (Cech, 2014) may be perpetuated in engineering education. Cech...
suggested that the culture of disengagement rests on “three ideological pillars: the ideology of
depoliticization, which frames any ‘non-technical’ concerns such as public welfare as
irrelevant to ‘real’ engineering work; the technical/ social dualism, which devalues ‘social’
competencies such as those related to public welfare; and the meritocratic ideology, which
frames existing social structures as fair and just” (ibid., p. 45). The results presented in this
paper illuminate articulatory processes through which the first two of these pillars of
disengagement can operate in engineering education as they construct ethics as different
from, and less relevant than purely technical concerns. I have identified six processes: 1.
disarticulating ethics from the core subject area, 2. articulating ethics and ethical reflection as
common sense, 3. articulating ethical reflection with colloquial language and thus inferior
quality and status, 4. disarticulating ethical reflection from scientific writing, 5. articulating the
core subject area of engineering with scientific writing and thus advanced and high quality,
and 6. failing to clearly articulate quality criteria for ethical reflection.

Luckily, since discursive articulation always is contingent and temporal, it can also be
changed. The results presented in this paper point to several ways in which teachers can
contribute to changing the discursive construction of ethics to render it more important in
engineering education. First, teachers can consciously avoid constructing ethics as
“something other” than the core subject area. Teachers can describe ethics as an important
topic in its own right, rather than one element among a broad range of “other” topics.
Second, teachers can avoid describing ethical reflection as characterized by colloquial
language that is of lower quality than scientific writing. A text on an ethical dilemma should
demand the same linguistic quality as a technical report on an engineering project. Third,
teachers can develop clear quality criteria for ethical reflection to avoid leaving ethical
reflection as a floating signifier. To do so, teachers will need access to both resources
(especially time) and competence development. Luckily, previous research provides tools to
support teachers in assessing ethical reflection. For example, Shuman et al. (2005) have
developed an assessment rubric that can be used to assess the quality of five components of
ethical reflection: identifying a dilemma, appropriate use of facts, analysis, use of multiple
perspectives, and resolution of the dilemma. Using such a rubric may help to construct
ethical reflection as a learning outcome that is as important, as advanced, and as learnable
as purely technical problem solving.

Due to the exploratory nature of the study, the results are not directly generalizable to
engineering education at large. However, the pervasiveness of the “culture of
disengagement” in different contexts of engineering education (Cech, 2014) suggests that
much engineering education also is dominated by discourses that construct ethics and other
societal concerns as marginal. The three articulatory themes presented in this paper (ethics
as “common sense”, ethics and ethical reflection as unscientific, and quality of ethical
reflection as a floating signifier) provide stepping stones for exploring the discursive
construction of ethics in other contexts in future research.

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Instructional practice learning through Instructional Incubator engagement

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Abstract: While student-centered learning has been shown to improve learning experiences in the engineering classroom, adoption of these evidence-based strategies has been slow. Research has shown that faculty beliefs about teaching and limited exposure to formal training influence effective implementation of evidenced-based instructional practices. Thus, in an effort to explore ways to implement long-term instructional change in engineering higher education, a graduate-level course, the Instructional Incubator (I2), was developed to expose future educators to instructional design and evidence-based practices. In the I2, student participants developed new biomedical engineering short-courses in an active learning classroom. For the first two iterations of the I2, we examined how this immersive experience influenced participants’ perceived teaching abilities and understanding before and after enrolling in the I2. Both I2 cohorts reported an increase in knowledge of engineering education related terms and showed a shift away from behaviorist and cognitive beliefs about teaching and learning.

Introduction

Increasing evidence supports the need to change instructional practice in science, technology, engineering, and math (STEM) classrooms to improve student learning (M. Smith, Jones, Gilbert, & Wieman, 2013; Stain et al., 2018). One strategy gaining traction in engineering educational practice is the shift to student-centered learning (Stain et al., 2018), which works to increase student-to-student and student-to-instructor interaction and cognitive engagement using various classroom strategies, such as active learning pedagogies (e.g. flipped classroom, think-pair-share, project based learning). However, the transition to student-centered engineering classrooms is still limited (Kim, Speed, & Macaulay, 2019; Nguyen et al., 2017). This may be due in part to individual instructor beliefs about teaching (Borrego, Froyd, Henderson, Cutler, & Prince, 2013) and limited formal training available to new faculty on evolving strategies for implementing student-centered learning (Brownell & Tanner, 2012; Burd et al., 2016). Studies seeking to understand the disconnect between instructor beliefs and the subsequent implementation of evidence-based practices have shown that creating a community for faculty to engage in pedagogical change may improve the implementation of evidence-based practices in classrooms (Shekhar & Borrego, 2017).

Recognizing that graduate students will play a critical role in long-term instructional change and are currently taking on more teaching roles as students (Austin, 2007; Smith, Sitomer, & Koretsky, 2014), efforts are being made to examine graduate student adoption of student-centered, evidence-based teaching practices (Goodwin, Cao, Fletcher, Flaiban, & Shortlidge, 2018). Goodwin et al.’s 2018 study of biology graduate students found that graduate
students that adopt evidence-based teaching practices may be playing a role in changing the culture of teaching practices on campuses. At the same time, while the majority of the graduate students showed an interest in evidence-based teaching practices, they were disappointed in the quality of support they were receiving for developing their teaching skills.

Looking to graduate students as the change agents for long term instructional change, we developed a structured, biomedical engineering (BME) graduate level course for students to develop their teaching skills, the Instructional Incubator (I2). The I2 addresses two challenges that have been identified as barriers to instructional change by 1) creating a community for individuals interested in pedagogical change (students, postdocs, and faculty) to engage in change together and 2) providing structured support for graduate students to develop courses and integrate evidence based practices as future engineering educators. The purpose of this research into practice study is to examine how participation in the research-based I2 influences participant perceptions of teaching and learning. Specifically, we explore student participant knowledge of, ability in, and beliefs on teaching and learning. We ask the following research questions:

1. How does participant knowledge of and ability in teaching and learning change as indicated by quantitative self-report survey data?
2. How do participant beliefs about teaching and learning change?

Background

The Instructional Incubator (I2)

The I2 is the first semester of a two-semester, graduate level sequence (I2-Module Sequence). In the two-semester sequence, graduate students, upper level undergraduates, post docs, and faculty create and implement 1-credit BME-in-Practice Modules (Malaga, Nu, & Huang-Saad, 2018). The Modules target first and second year students to engage them in BME practice early in their academic career.

The I2, offered in the fall semester, is an experiential course where participants learn about student learning theory and curriculum design, while developing their own modules through the instructional design process. Participants collectively discuss evidence-based pedagogical practices in engineering education and advances in learning theory. For the instructional design process, participants engage in “Instructional Discovery” (ID) where they interview BME stakeholders (e.g. BME undergraduates, practicing biomedical engineers, instructors) and learn about the current state of BME in practice. This process includes focusing on problems of the field, cutting edge research used to solve these problems, professional practice standards, current technical tools used, and industry standards and vocabulary. Integrating what they experience in the classroom and the student learning literature, participants form teams and use the needs identified by stakeholders to create 1-credit (4 week) “BME-in-Practice” modules. Participants have the option to team teach their “BME-in-Practice” modules in the following winter semester with guided mentorship.

Instructional Incubator’s Motivation and Theoretical Grounding

The creation of the I2 was motivated by calls to transform undergraduate education. (American Society for Engineering Education, 2013; National Academy of Engineering, 2013). Research around implementation of student-centered learning strategies in engineering classrooms has shown positive results for students (Mostrom & Blumberg, 2012). Of those student-centered learning strategies, active learning (AL) has been shown to be particularly efficacious (Christie & Graaff, 2017; Freeman et al., 2014). AL approaches have been shown to increase student engagement in the classroom, increase average grades and pass rates, deepen student understanding of course material, promote self-efficacy, and increase student confidence in their abilities (Kim et al., 2019; Marone et al., 2018). Although it is apparent that AL benefits students, instructors often have difficulties implementing these strategies. These difficulties could be partially attributed to a number of
factors. In STEM courses, the most commonly implemented education practice is lecturing, where students passively listen while the instructor speaks (Kim et al., 2019). Many of today’s academics were educated in this style when they were going through their coursework (Kim et al., 2019) and excelled in this environment. Faculty therefore, often retain this status quo in teaching in addition to citing lack of training and time as barriers for implementing new teaching practices (Kim et al., 2019).

By creating a space for participants to experience curricular change through the student-centered learning strategies used in the I2 and then subsequently implement curricular change in their Modules, the course sequence employs the tenets of situated learning theory’s communities of practice (Wenger, Mcdermott, & Snyder, 2002) and constructivism (Newstetter & Svinicki, 2011). Additional research suggests that it is possible to bring about instructional change by changing instructors’ beliefs about teaching and learning to better align with the intentions of research-based reforms (M Borrego et al., 2013; Kember, 1997). One effective way for changing beliefs is creating opportunities for instructors to experience research-based practices while in a student role to internalize the benefits of these practices (Fetters et al., 2002). Thus, the I2 was created to expose future instructors to research-based practices in an experiential setting to effectively change their beliefs about teaching and learning.

**Instructional Incubator's Integration of Active Learning**

The I2 was specifically designed to model research-based student-centered learning strategies (Maura Borrego, Cutler, Prince, Henderson, & Froyd, 2013) in the classroom for participants. For example, I2 participants interviewed other students and BME stakeholders. Participants were required to observe other faculty at the University and reflect on student engagement. Student learning theory literature was discussed in small groups and as a class. The collaborative jigsaw method (Lom, 2012) was also used as a comparative approach to small group discussion. The course met two times a week. One day was dedicated to active discussion and the other was devoted to in class project-based learning.

**Methods**

Our study employed a mixed methods approach (Kajfez & Creamer, 2014), using quantitative data to see patterns in perceived gains and qualitative data for insight into participant perceptions of the 30 students who have participated in the incubator course over the first two years (19 in AY17.18 and 11 in AY18.19). An online survey was used to collect data from student participants in the first two years of the I2 (AY17.18 & AY18.19).

**Data Collection**

A Qualtrics survey was used to collect quantitative and qualitative data at the start and end of the I2. Participants whose data are analyzed in this paper ranged from fourth-year undergraduate students through doctoral candidates in both years of implementation. We asked participants to provide anonymous identifiers of their choosing on pre- and post-course surveys, allowing us to match data across the course, but allowing for anonymity between the participants and the last author researcher, who taught the course. Using this survey strategy, we collected 4 paired survey results for AY17.18 and 10 for AY18.19, giving us response rates of 21% and 91%, respectively. We speculate that the low response rate in AY17.18 can be attributed to students using different anonymous identifiers from pre- to post-course surveys. In the AY17.18 data, students may have forgotten their anonymous identifier, as there were some identifiers in the post-survey that were not consistent with pre-survey identifiers. For AY18.19, we accounted for this by providing participants a list of the anonymous identifiers used in the pre-survey at the beginning of the post-survey.

In the survey, respondents were asked to self-report their teaching abilities by responding to a categorical question about their previous experiences and then rating their perceived effectiveness in those teaching roles in a Likert scale response. They were then asked about
their abilities to perform teaching tasks and knowledge of various engineering education
terms using Likert scale questions. Respondents were also asked two open-ended questions
which asked them to describe learning and effective teaching in engineering.

Data Analysis

Survey responses were analyzed with Microsoft Excel and Qualtrics. Quantitative responses
were paired using anonymous identifiers and categorized by academic year (2017-2018 or
2018-2019). For the question on previous experiences, we totaled the number of participants
who indicated a given experience and then performed descriptive statistics on the Likert
scale responses. To analyze the remaining Likert scale responses (abilities to perform
teaching tasks and knowledge of terms), we averaged the responses for pre and post-
surveys for data display purposes, separating them by academic year (17.18 or 18.19). We
then utilized paired t-tests to determine significant results by academic year.

To analyze the qualitative survey results, we used a deductive coding approach with focused
codes (Cho & Lee, 2014) meant to gauge the influence of the I2 on participant beliefs
regarding teaching and learning. To do this, we based our codes on learning theories which
have been previously described as applicable to engineering education (Newstetter &
Svinicki, 2011). We adapted these descriptions to fit the coding purposes of our qualitative
data (Table 1).

<table>
<thead>
<tr>
<th>Code</th>
<th>Newstetter &amp; Svinicki definition</th>
<th>Adapted definition</th>
<th>What it is</th>
<th>What it is not</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Behaviorist</strong></td>
<td>Learning is the creation of stimulus-response connections through exposure, repetition, and consequences.</td>
<td>Learning is a direct response from a mental database of possible responses in reaction to a problem, question, or challenge.</td>
<td>Taking in information or stimuli without processing it.</td>
<td>Interpreting, processing, or analyzing information.</td>
</tr>
<tr>
<td><strong>Cognitive</strong></td>
<td>Learning is the process of creating mental models.</td>
<td>Learning is the development of a network of mental models.</td>
<td>Moving information from short term to long term memory by incorporating it with previously established knowledge. Using real world examples to process the content.</td>
<td>Regurgitation of facts, rote memorization, or knowledge owned by a group</td>
</tr>
<tr>
<td><strong>Situated</strong></td>
<td>Learning is moving from peripheral forms of participation in a community to full participation facilitated by apprenticeship opportunities to observe and then practice activities.</td>
<td>Learning is the development of an ability to participate or contribute in a community of practice, by developing knowledge or skills used by the community.</td>
<td>Increasing participation or exploring identities in a community of practice. This can be through real world examples or teamwork activities that mimic professional situations.</td>
<td>Independent of context or an activity performed only by an individual.</td>
</tr>
</tbody>
</table>

Then, the first three authors coded the data independently and subsequently discussed until
consensus was reached for each response. Achieving consensus consisted of each
researcher presenting their reasoning for their selected code, discussion about coding criteria and consistency of applying the criteria across responses, and subsequent selection of the assigned code as a group.

In the open-ended survey questions, responses varied in length and, as such, the researchers coding responses decided together that some responses did not provide enough context to fully understand the respondent’s views on teaching or learning (e.g. “Learning is acquiring skills, knowledge, and experiences.”) Because these responses were part of an anonymous survey and not collected as interviews, we could not follow up with such responses to get more information. In these cases, we chose to code them as not applicable and remove them from the analysis rather than ascribing a code with too little information.

Results

Quantitative Results on Self-Report Knowledge and Ability Data

**Ability.** In the pre-survey, participants were asked to describe their previous teaching experiences as well as rate how effective they felt as instructors in those situations. All 14 respondents had at least some form of informal teaching experience. More formal teaching experience varied (e.g. teaching or assisting in an undergraduate or graduate course), but overall, respondents with teaching experience in both implementation years scored themselves as between neutral and very effective on a five point Likert scale (1 = very ineffective, 5 = very effective).

We also asked respondents to assess their confidence in performing various teaching tasks using a five point Likert scale (1 = not confident at all and 5 = very confident). Tasks were separated in two groups: instructor centered (Figure 1A) and student centered (Figure 1B).

![Figure 1: Confidence performing instructor and student centered teaching tasks, *p<0.05, **p<0.01](image-url)

Instructor centered tasks included: teaching an undergraduate class, leading class discussion (in and outside your expertise area), and lecturing on a topic (in and outside your expertise area). Student centered tasks included: designing activities to augment learning, being responsive to student needs, engaging all students, and adapting lesson plans during instruction. Overall, AY18.19 respondents felt more confident in both types of tasks coming into the course, but paired t-tests indicate that there was limited confidence gained over the time of the course. In the first year (AY17.18), participants expressed fairly low confidence...
entering the course, but showed significant improvement in confidence in a number of tasks at the end of the course. (Figure 1).

**Knowledge.** Further, we examined the gains in familiarity with terms related to research and strategies which would signal respondents’ ability to pursue additional resources in evidence-based teaching practices. Respondents were asked to rate their familiarity with 10 terms relevant to the I2 course and engineering teaching (1 = very unfamiliar to 5 = very familiar). Before starting the course, both cohorts felt more familiar with terms like: project based learning (PjBL), problem based learning (PBL) [data not displayed], and AL (Figure 2) as indicated by high Likert responses (average above 4 in both years) in the pre-survey. We also examined gains in familiarity with the ten terms, separating them by implementation year. For the sake of brevity, only significant results are displayed in Figure 2. Significant improvement in familiarity which overlaps in both AY17.18 and AY18.19 of the course are AL, learning theories, situated learning, pedagogical content knowledge, and engineering education research. AY17.18 respondents also expressed more familiarity with classroom discourse at the end of the course, while AY18.19 respondents expressed more familiarity with pedagogy.

![Figure 2: Familiarity with engineering education and related vocabulary, *p<0.05, **p<0.01](image)

**Qualitative Results on Participant Beliefs**

**Beliefs.** Beliefs about learning before and after taking the course were probed through two open ended questions about teaching and learning (Table 2). We report the percentage of responses categorized as each theory in Table 2. Results indicate a minor shift in descriptions of both teaching and learning. The number of responses categorized of the 14 total responses is also provided as these affect the percentage reported on the responses placed in each of the learning theory categories.

**Discussion**

The self-report pre- and post-survey data collected provided insight into how participation in the research-based I2 influences participant perceptions of teaching and learning. These results will allow us to iterate on the I2 experience to improve I2 participant learning and make class time more effective. It may also provide insight into aspects of this teaching training strategy which would be useful in improving teaching beyond the institution at which it is implemented currently.

In the first two years, participants enrolled in the course had varying teaching experiences. Many had taught informally or participated in educational outreach. Interestingly, the participants responding in AY17.18 year rated their effectiveness as instructors in the neutral to somewhat effective range of responses while the AY18.19 cohort rated themselves slightly
higher. This generally higher self-assessment in the pre-course survey can also be seen in the AY18.19 cohort for questions regarding their ability and knowledge as instructors. This difference in self-rated effectiveness, familiarity with terms, and confidence in teaching tasks may be indicative of participant confidence in themselves as instructors in each cohort, though more investigation is warranted. In the future, we will leverage research on teaching self-efficacy in engineering (Yoon Yoon, Evans, & Strobel, 2014) and pedagogical content knowledge (Fernández-Balboa & Stiehl, 1995) for examining differences in teaching confidence and measurable ability to broaden data beyond self-reports of experience as an indicator of confidence.

Table 3: Participant beliefs in response to questions about perceptions of teaching and learning

<table>
<thead>
<tr>
<th>Question</th>
<th>Theory</th>
<th>Pre</th>
<th>Post</th>
<th>Example Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>How would you describe effective teaching in engineering?</td>
<td>Cognitive</td>
<td>57%</td>
<td>46%</td>
<td>Effective teaching is enabling/supporting learning as well as the development of mental models in the learners so they can build on them in future.</td>
</tr>
<tr>
<td></td>
<td>Situated</td>
<td>29%</td>
<td>27%</td>
<td>Effective teaching in engineering is teaching that engages students and prepares them to be independent thinkers and doers.</td>
</tr>
<tr>
<td></td>
<td>Bridging Situated and Cognitive</td>
<td>14%</td>
<td>27%</td>
<td>I think effective teaching follows the I do, we do, they do method. Where the instructor shows how the skill or project is done and then the students begin working on it with help and then on their own. I also think hands on work is very valuable for engineers as well as working in groups.</td>
</tr>
<tr>
<td>Total Responses Coded</td>
<td>14</td>
<td>11</td>
<td></td>
<td></td>
</tr>
<tr>
<td>How would you describe learning?</td>
<td>Cognitive</td>
<td>84%</td>
<td>64%</td>
<td>Learning is the process by which a person comes to the ability to do, think, process, interpret, or otherwise handle a piece of the world that they could not navigate before learning has occurred.</td>
</tr>
<tr>
<td></td>
<td>Situated</td>
<td>8%</td>
<td>9%</td>
<td>Learning is the accumulation of knowledge through experiences.</td>
</tr>
<tr>
<td></td>
<td>Bridging Cognitive and Situated</td>
<td>0%</td>
<td>27%</td>
<td>Learning is not only being able to understand and identify something that was taught in class, but being able to apply that knowledge for further use following the instruction.</td>
</tr>
<tr>
<td>Behaviorist</td>
<td>8%</td>
<td>0%</td>
<td></td>
<td>Learning is the process of exchanging new knowledge from one person to another. The teacher and the student can learn from each other as well.</td>
</tr>
<tr>
<td>Total Responses Coded</td>
<td>13</td>
<td>11</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

AY17.18 respondents reported increases in their confidence to lecture outside their area of expertise, lead discussions, be responsive to student needs, and engage all students. These results indicated increased confidence in both instructor and student-centered instructional tasks. AY18.19 respondents rated themselves more confident in all teaching tasks before entering the course than AY17.18 respondents. This higher confidence could be the main reason why we found no significant increases in their confidence in the teaching tasks discussed in the survey, with the exception of the most general task: teaching an undergraduate course. Furthermore, while not statistically significant, students in AY18.19
reported slight decreases in confidence to perform student-centered tasks like: being responsive to student needs, engaging all students, and adapting lesson plans during instruction. It is possible that increased awareness of the many considerations involved in teaching may have negatively affected their outlook on their abilities to perform certain teaching tasks. Future work will use data collected on the same perceived abilities after the Modules, where participants implement their designed courses, to investigate the influence of the mentored teaching experience on confidence levels in the same students.

Unlike the stark difference in ability rating improvement, respondents in both years reported increased knowledge of many engineering education related terms at the end of participation. Further similarities in the data from the two cohorts included high (average above 4) pre-survey ratings of familiarity with terms like AL, PBL, and PjBL. These high ratings could be linked to exposure to these strategies or terms from their own previous experience in engineering classrooms. While the terminology may be familiar to participants because of the push to implement them in engineering classes (Mills & Treagust, 2014), their implementation along with other student-centered strategies are still limited. Further work to investigate the development of participants’ conceptions of AL, PBL, and PjBL throughout participation in the I2-Module sequence will offer additional insights.

Further, the courses diverged in familiarity with two terms: classroom discourse (AY17.18 significant) and pedagogy (AY18.19 significant). While it is unclear why respondents in AY17.18 but not AY18.19 felt more familiar with classroom discourse, it should be noted that more examples of evidence-based pedagogy were provided in AY18.19 at the cost of in-depth discussion of classroom discourse. Future work to analyze data collected in the Modules portion of the sequence on participants’ use of teaching practices which demonstrate knowledge of these terms could provide additional support of the reported gains in the I2 course.

Finally, we observed a shift in the way participants described both teaching and learning. Highly cognitive or behaviorist responses were lower in the post-survey responses and responses that had aspects of both cognitive and situated learning theories were higher. We attribute the shift in responses partially to increasing comfort with the terminology one might use to describe teaching and learning through the I2 course, as well as their first-hand experience with learning strategies tailored to expand beyond or improve the traditionally cognitive teaching strategies in engineering classrooms (Kim et al., 2019; Newstetter & Svinicki, 2011).

**Conclusion**

Our study suggests the potential value of the I2 semester for graduate students interested in pursuing careers in academia. Participants indicated perceived increases in knowledge and ability to teach engineering content. Their responses also provided insight on relevant future work to analyze data collected throughout the Module portion of the sequence. Furthermore, beliefs of teaching and learning appear to have shifted and perhaps matured through participation in the course. Finally, this work provides a number of directions for further investigation to improve the experience of participants in this course and future engineering educators wishing to provide similar curricular change support to their departments. Future research on the I2 course will investigate differences in participants’ self-reports on ability or knowledge and other established outcomes measures related to those constructs as well as investigating the change in familiarity with pedagogical strategies like PBL and PjBL through I2 participation in a more nuanced, qualitative study.

**References**


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Peer review of teaching merits in academic career systems: a comparative study

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Abstract: This paper investigates peer review of teaching merits in promotion processes at two Swedish technical universities. At KTH, two external experts evaluate both scientific and teaching merits, while Chalmers invites three experts for scientific and one for pedagogical evaluation. 50 successful promotion cases, containing 126 expert statements, are investigated quantitatively and qualitatively. The analysis shows that neither university devotes the same attention to assessing teaching as scientific merits. In 2/3 of the cases, less than 1/3 of the text is devoted to evaluating teaching merits. Half the KTH cases are settled based on less than one page evaluating teaching. In pedagogical evaluations at Chalmers, teaching qualifications are broadly conceptualised including collegial and scholarly aspects. At KTH, the experts with Swedish affiliations demonstrate broader conceptualisations of teaching than the international experts do. This is interpreted as expressions of two different evaluation cultures, one scientific-international and one pedagogical-national. The legitimacy of these practices is considered.

Introduction

Academic career systems are seen to have an imbalance in the recognition of research and teaching merits, in favour of research, and this is identified as a fundamental barrier to the enhancement of higher education (MIT 1949; Graham 2012, 2015; Edström 2017; Geschwind & Broström 2015; Ryegård, Olsson & Apelgren 2010; European University Association, 2019). One difficulty in addressing this imbalance is that conditions for evaluating research and teaching are different. When it comes to evaluating research, there are reasonably accepted values for output and academic impact, and well-established practices to evaluate such merits through peer review. While the actual measures are imperfect and always under debate (see for instance Bornmann & Daniel, 2005), the agreement still seems sufficient for the practical purpose of comparing the research merits of competing candidates, or even to evaluate individuals towards some standards. As there is less consensus when it comes to how teaching competence can be documented and evaluated, there is a need to learn from the experiences of universities that are trying to develop more appropriate career systems.

Despite the expansion of different contexts within which academic scholarship is peer reviewed (Langfeldt & Kyvik, 2011), research exploring how academic teachers are recruited
has been scarce (Hort, 2009), as has research on criteria used by e.g. search committees (Meizlish & Kaplan, 2008). Moreover, research that does focus on peer review in academic hiring is largely concerned with evaluation of research rather than teaching merits.

Recent Swedish studies of peer review of teaching merits in academic hiring show that reviewers devote less textual space to comment on candidates’ teaching competence than they do on scientific competence (Levander & Riis, 2016; Mårtensson et al., 2018). Further, they more commonly address quantitative aspects of teaching competence, such as years of teaching experience, number of courses taught and number of supervised doctorates, while qualitative aspects are less articulated (see for example Gunvik-Grönbladh & Giertz, 1998; Hallerdt, 1987; Levander, 2017; Levander et al., 2019; Levander & Riis, 2016). There are also indications that instructions and guidelines matter relatively little for the way teaching competence is conceptualized in expert evaluation reports. Instead, the reviewers’ qualifications, assignment and academic culture have strong implications (Gustafsson, 2014; Levander, 2017; Levander et al., 2019). It is also found that reviewers from Swedish universities articulate more aspects of teaching competence than international reviewers do (Levander et al., 2019). Furthermore, reviewers appointed as special pedagogical experts convey a wider notion of teaching competence than scientifically assigned reviewers (Bolander Laksov, 2018; Levander, 2017). Most of these previous studies in Sweden have been situated in comprehensive universities.

The context - two Swedish technical universities

In Sweden, the Higher Education Ordinance governing faculty hiring and promotion, states: “As much attention shall be given to the assessment of teaching expertise as to the assessment of research or artistic expertise.” Thanks to the 250-year old principle of public access to official records in Sweden, the documents regarding appointment and promotion cases are openly available, making it a context where the actual practices can be studied.

This study compares promotion practices at two Swedish technical universities, KTH Royal Institute of Technology (KTH) and Chalmers University of Technology (Chalmers). They are similar in many respects, being the two single-faculty technical universities established in Sweden during the 19th century (a third institution for higher engineering education was not established until the 1960’s). KTH is situated in capital Stockholm and larger, with about 15000 students and 1580 academic staff of which 307 full professors. Chalmers is located in Gothenburg, with about 10000 students and 1292 academic staff of which 214 full professors; all figures from 2017. Both are research universities with more than two thirds of the budget for research. Together, KTH and Chalmers produce 56% of Swedish PhDs in engineering sciences as well as 20% of PhDs in natural sciences. On the master level, they provide over half of all technical education in Sweden, with over ten other institutions producing the rest.

In both universities, tenure track-style promotion is now more common than announced professorships. Teaching qualifications are assessed based on pedagogical portfolios and both universities provide comprehensive templates for writing them. As in most Swedish universities, it is also an eligibility requirement to have 15 ECTS credits (10 weeks) education in Teaching and Learning in Higher Education (Lindberg-Sand & Sonesson, 2016). The career structures are slightly different, however. Chalmers has three levels at the top, Professor, Professor not holding a chair, and Associate Professor, while KTH has Professor and Associate Professor (Chalmers, 2013; KTH, 2013; KTH, 2018). To evaluate candidates’ research and teaching portfolios, both universities appoint external peer reviewers. The difference, of particular interest here, is that KTH appoints two experts to evaluate both research and teaching, while Chalmers uses four experts per case, one to evaluate teaching and three to evaluate the scientific merits. KTH lets the experts use any format, while Chalmers provides templates, different for scientific and pedagogical evaluation. In both universities, the internal committee makes a final recommendation informed by the written expert statements and interviews with candidates.
Aim and research questions

The aim of this study is to investigate how teaching merits are evaluated when reviewers have different qualifications and evaluation assignments: when they are evaluating both scientific and teaching merits (integrated evaluation) or when scientific and teaching merits are evaluated by separate experts. The main research question is (RQ1): Given the use of integrated or separated evaluations, what differences can be seen in how candidates’ teaching merits are evaluated by the experts? Guided by the ethos that “as much attention shall be given to the assessment of teaching expertise” and inspired by previous work, we decided to compare the amount of text devoted to teaching and research. We also investigate the themes that the experts explicitly refer to in relation to teaching merits. The assumption is that when an aspect is explicitly mentioned, or not mentioned, it reveals something about the expert’s conceptualisation of teaching qualifications and corresponding valuation. Likewise, if something is mentioned in negative terms it reveals some expectation that was not met. This gives two sub-questions (RQ2): In the expert statements, how much text is devoted to assessing teaching merits and scientific merits? and (RQ3): How is teaching competence conceptualised, i.e. what aspects are mentioned by the experts, in neutral, positive or negative terms?

Methodology

We requested documentation for all successful promotion cases for Associate Professors and Professors completed during the academic year 2017/18. (Unfortunately, no representative category of unsuccessful cases exists, as it is likely that most applicants rather refrain from applying or withdraw in various stages.) Each case contains external expert statements evaluating the candidate’s application, and the decision protocol of the committee. We did not request the applications, as the focus here is more on the evaluators and the evaluation process itself. Further, it was beyond our capacity in this study to analyse applications, since a teaching portfolio with appendices can be numerous pages.

The material contains 36 promotion cases at KTH, of which 18 for Professor and 18 for Associate professor. Each candidate is evaluated by two experts, which gave us 72 statements. At Chalmers, we included 4 cases for Full Professor and 10 for Professor not holding a chair. Two additional cases were excluded (one had been through a four-year process which could not fully be understood from the documents, one lacked a key document). At Chalmers, each candidate is normally evaluated by four experts, but one case was based on only three statements, and in another we excluded an illegible statement. This left 54 statements from Chalmers, 41 evaluating scientific merits and 13 evaluating teaching merits only. Hence, the material contains in total 50 cases and 126 statements.

The analysis of the statements started with a quantitative phase, counting the words devoted to the evaluation of scientific and teaching merits, respectively. Other text was excluded, such as when experts thanked for the assignment, described their own merits, declared that they had no conflict of interest, or repeated given instructions. Next, we used a content analysis method to systematically describe the meaning of this qualitative material, by classifying instances of the categories of a coding frame (Schreier, 2012). Our thematic coding framework was adapted from previous work by Levander (2017) and contains 11 themes, see Table 1. The expert statements were classified according to which of these aspects of teaching competence were mentioned, and whether this was in neutral, positive, negative or mixed terms. To make interpretations more consistent, two of the authors (Edström and Engström) first coded a number of statements together during continuous discussions (15 hours in total). It was also at this stage that the coding framework was adapted by adding the themes Nexus and Diversity. After the initial phase, they mainly worked separately discussing some cases on email. Finally, they returned to double-check samples of each other’s coding, which indicated a high degree of agreement.
Table 1: Thematic framework (adapted from Levander, 2017)

<table>
<thead>
<tr>
<th>Theme (Short name)</th>
<th>Refers to</th>
<th>Sample quotes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teaching (Teaching)</td>
<td>Teaching experience on various levels, forms of teaching, undergraduate supervision, teaching quality</td>
<td>&quot;She has a broad experience from teaching at all levels in the higher education.&quot;</td>
</tr>
<tr>
<td>PhD Supervision (PhD Supervision)</td>
<td>Experience in supervising PhD students, quality of supervision</td>
<td>&quot;She has as of today supervised three PhD students to completion as main supervisor.&quot; &quot;Her PhD students have gone on to impressive careers.&quot;</td>
</tr>
<tr>
<td>Management of Education (Management)</td>
<td>Responsibilities in courses and programs, Director of Studies and similar</td>
<td>&quot;She has been responsible of the development, organisation and administration of courses.&quot;</td>
</tr>
<tr>
<td>Development of Education (Development)</td>
<td>Program and course development</td>
<td>&quot;...his course in [subject] where he redesigned the whole course material that contains not only plenary lectures but also different types of home assignments.&quot;</td>
</tr>
<tr>
<td>Commissions of Trust, Service (Service)</td>
<td>Activities in society or the scientific community</td>
<td>&quot;She has been an invited external critic for PhD examinations at a number of respected universities.&quot; &quot;He has twice participated as a teacher in Summer Schools.&quot;</td>
</tr>
<tr>
<td>Teaching Philosophy (Philosophy)</td>
<td>Reflective writing on teaching, supervision, educational development, own development, etc</td>
<td>&quot;He refers to different authors and their ideas on pedagogy and continues to show how he has implemented these in his own teaching by providing enlightening examples.&quot;</td>
</tr>
<tr>
<td>Teacher Training (Training)</td>
<td>Courses on teaching and learning in higher education according to the 15 ECTS credit requirement</td>
<td>&quot;First, I note that he has stated that he has taken courses in teaching and learning in higher education comprising at least 15 credits and hence he has fulfilled the requirement&quot;</td>
</tr>
<tr>
<td>Testimonials and Recognition (Testimonials)</td>
<td>Awards, course evaluations and other feedback, learning from course evaluations</td>
<td>&quot;The teaching feedback is very positive&quot; &quot;He has noticed a positive trend in the evaluation and he is also well aware of what can be done for improving the course further.&quot;</td>
</tr>
<tr>
<td>Scholarly Interaction, Scholarship of teaching and learning (Scholarship)</td>
<td>Theoretical knowledge within the pedagogical area or publications or reports in education</td>
<td>&quot;He has notably successfully implemented the constructive alignment method for teaching and course design, where intended learning outcomes, learning activities and assessments have to closely align.&quot; &quot;The applicant has published one article in the area of education&quot;</td>
</tr>
<tr>
<td>Teaching Research Nexus (Nexus)</td>
<td>Connection between research and teaching</td>
<td>&quot;It is also very laudable that he brings his current research into the classroom and enables through his software to give the students access to real naturalistic data and use that to address current research and policy issues.&quot;</td>
</tr>
<tr>
<td>Equality and Diversity (Diversity)</td>
<td>Equality, gender, diversity</td>
<td>&quot;He is definitely aware of diversity and gender issues at KTH and how to address them as a leader.&quot;</td>
</tr>
</tbody>
</table>

Results and analysis

Word count

The average KTH statement has 962 evaluation words, while the corresponding number for Chalmers is 807. One explanation for the slightly shorter statements at Chalmers is that the invitation to the expert asks for a 1-3 pages, in a template with headings such as “An assessment of the candidate’s competence, quality and pedagogical skills”, which can allow more effective writing. At KTH the experts write without a given template and often include headlines and other structuring elements in the text.

Summing up the word count per case showed that the average KTH case contained 1377 words devoted to scientific and 548 to teaching merits, while Chalmers cases contained on average 2030 words on scientific and 970 on teaching merits. The higher word count for Chalmers is completely expected since it normally contains four statements per case and
KTH two. In Figure 1, all cases are ordered by their total word count related to teaching (summing up the statements for that case).

Figure 1. Word count per case, ordered by sum of words on teaching merits (blue). Words on scientific merits are grey for Chalmers cases, orange for KTH.

The graph shows that 21 cases (18 at KTH and 3 at Chalmers) contain fewer than 500 words on teaching merits. In other words, 50% of the cases at KTH and 21% of the cases at Chalmers are settled based on one page of text or less to evaluate teaching merits. Note that this is the sum of words written by two to four reviewers. The case with the lowest number of words on teaching reaches half a page (248 words, KTH). Only 16% of the cases (2 at KTH and 6 at Chalmers) are based on over 1000 words, or about two pages, on teaching merits.

It could be argued that counting words is crude, as what really matters is how well the evaluation is made. However, even if it is a poor measurement, we see no immediate reason why it should not be equally poor on both sides. Therefore, and given the legal formulation that as much attention shall be given to the assessment of teaching as to the assessment of research, it makes sense to compare the proportion of words devoted to teaching and research, respectively. See Figure 2.

Figure 2. Word count per case, ordered by percentage of words on teaching (blue). Words on research merits are grey for Chalmers and orange for KTH cases.

We see that only one case has more words on teaching than on scientific merits. If we consider 40/60 as a sufficiently balanced ratio, there are 6 such cases (4 at KTH and 2 at
Chalmers), or 12% of the whole material. In 34 cases, or 64% of Chalmers cases and 69% of KTH cases, less than a third of the total text is devoted to teaching merits.

**Frequency of themes**

In the following, the conceptualisation of teaching qualifications is analysed, operationalised by the themes that are mentioned. The three types of statements are analysed separately: scientific at Chalmers, pedagogical at Chalmers, and integrated at KTH.

**Analysis of Chalmers statements, scientific and pedagogical**

The experts making scientific evaluations at Chalmers are typically professors (a few use the title Head of research institute). Two thirds are affiliated in international institutions and one third in Sweden. Although these experts are not asked to assess teaching merits, and the template lacks a designated space for bringing it up, most scientific statements still mention Teaching (76%) and PhD Supervision (66%), see Figure 3. It seems that many experts see teaching and doctoral supervision as inseparable from research, or that they are accustomed to providing assessment of both scientific and teaching merits.

![Figure 3. Frequency of themes – Chalmers scientific statements.](image)

Three further themes, Philosophy, Service, and Development, feature in about 25% of statements. The scientific evaluators might perhaps be expected to address themes with a bearing on research – Nexus could be particularly relevant, and Scholarship could be brought up for candidates who have published also within education. These themes occur however in fewer than 10% of the statements. In fact, half of the mentions are within two cases so outside these, Scholarship and Nexus are almost negligible in this category of statements.

The picture is clearly different for the pedagogical statements. We note that everyone appointed as pedagogical evaluator has Swedish affiliation. About half could be called educational developers, i.e. specialists in teaching and learning centres (often engaged in providing the required 15 ECTS of educational courses). The others are technical faculty with a profile in subject didactics, or academics in the field of education. 29% are Professors and 36% Associate professors, while the rest hold other positions (e.g. educational developer in non-academic positions, lecturer, retired).

The pedagogical experts address more themes; no less than eight themes feature in a majority of statements, see Figure 4. The most common themes are Teaching and PhD Supervision. Next the experts check that the candidate fulfils the 15 ECTS credits (Training). Interestingly, 31% of the pedagogical evaluations mention Nexus. While this still makes it one of the less frequent themes in pedagogical statements, it is more than 3 times as
common in a pedagogical evaluation than a scientific one. As we will see below, it is also 3.7 times more common than in the integrated statements at KTH.

![Figure 4. Frequency of themes – Chalmers pedagogical statements.](image)

More often than the other categories of statements, the pedagogical ones contain critical comments, or mixed evaluations discussing both positive and negative aspects. Most often when the evaluator finds something to criticise or notices something as absent it applies to: the quantity of experience in Teaching; lack of course evaluations (Testimonials); the required courses on teaching and learning not completed (Training); a lack of depth in the teaching philosophy statement or objections to some part of it; or lack of walking-the-talk of the espoused ideas (Philosophy).

**Analysis of KTH statements, integrated**

![Figure 5. Frequency of themes in KTH statements (integrated).](image)

The experts who evaluate both research and teaching at KTH mention mainly seven themes, thus showing their expectations on teaching merits, see Figure 5. At least 90% of statements address PhD Supervision and Teaching, while Philosophy, Development, Training, and Testimonials occur in over half the statements. Management is mentioned in about 40% and other themes in fewer than 25% of the statements. On the rare occasion that negative or mixed evaluations are made, the targets are too little experience in PhD supervision, or lack of course evaluations (in Testimonials). As these experts are asked to evaluate both teaching and scientific merits, it could perhaps be expected that they also consider the relationship between those activities (Nexus). This perspective is however the least frequent, present in only 8% of the statements at KTH.
All experts engaged by KTH are professors and 55% are affiliated with universities outside Sweden. When we separate evaluators with international and Swedish affiliation, an interesting difference is evident, see Figure 6a and 6b.

![Figure 6 a and b. Frequency of themes in KTH integrated statements. Experts with international affiliation to the left (6a) and Swedish to the right (6b).](image)

We see that the Swedish evaluators’ statements bring up far more themes than the international ones. In fact, the evaluations by experts with Swedish affiliation (Figure 6b) resemble more the special pedagogical statements at Chalmers (Figure 4) than those made by their international colleagues (Figure 6a).

**Discussion and conclusions**

The quantitative text analysis, *comparing the amount of text to assess teaching merits and scientific merits (RQ2)*, shows that in general much less attention is devoted to teaching merits than to scientific merits. Only 12% of the cases could be considered fully balanced (within a 60/40 word count ratio). In two thirds of the cases, less than one third of the text was devoted to teaching merits. This suggests that the ambition in the Swedish Higher Education Ordinance, that “*as much attention shall be given to the assessment of teaching expertise as to the assessment of research...*” is not fulfilled. Turning to the absolute numbers of words, we further note that the promoting process for half of the Associate Professors and Professors at KTH involved only between one half and one page of text evaluating their teaching qualifications.

When it comes to *how the experts conceptualise teaching competence (RQ3)*, we see that in all categories of expert statements, the two most common aspects of teaching qualifications are teaching and PhD supervision. They are even brought up in the *scientific* assessments at Chalmers. The *pedagogical* assessments also pay attention to more collegial or scholarly efforts, such as educational development and management, service and scholarship, and they also take a more critical approach with both positive and negative comments. At KTH, the integrated statements mention teaching merits almost only in positive terms. Here, in addition to PhD supervision and teaching, teaching philosophy, development, teacher training and course evaluations are mentioned in over half of the statements.

We found it particularly interesting that the teaching-research nexus is hardly in focus at all, and especially that the integrated evaluations at KTH, which *could* have paid attention to this, were clearly the weakest in this respect. The opportunity to address this aspect could otherwise have been a persuasive argument for evaluating scientific and teaching qualifications together. Also when the experts making scientific assessments at Chalmers do bring up teaching merits, despite not being asked to, it is mostly conceptualised as something separate, not related to research.

By separating the KTH evaluations based on whether the experts had Swedish or international affiliation, we could show that Swedish experts behaved more like the pedagogical evaluators at Chalmers, who are also Swedish. It seems that the national
context plays an important role. Our interpretation is that there are two different evaluation cultures at play. Whereas scientific evaluations are rooted in the traditions of international disciplinary communities, the pedagogical evaluations are clearly influenced by a Swedish discourse on teaching and learning. This has been shaped over a couple of decades by national regulations, required courses for faculty, a lively network of educational developers, so called pedagogical competence ladders in numerous institutions, and a course for prospective pedagogical evaluators resulting in a list of experts who are trained for making this form of assessment of teaching merits. Most of the pedagogical experts at Chalmers have some background in these practices, and to some extent this also seems to influence the Swedish academics who make integrated evaluations for KTH. One indication that this is a particular, relatively well-defined discourse is the prevalence of critical comments, revealing clearer expectations on what constitutes teaching competence. We don’t think this discourse is limited to Sweden, as we also recognise it in international communities. But based on our material, we can say that the typical international expert is not part of the same discourse on teaching competence – not because they are international but because they are first and foremost distinguished representatives of the disciplinary scientific communities. This is reflected in their statements, which conceptualise teaching more narrowly and have comparatively little to say about it.

The overall question is then about the implications of separated or integrated evaluation (RQ1). This study shows that teaching merits are generally more meticulously evaluated at Chalmers, due to their use of special pedagogical experts. This is therefore a way for Chalmers to further the teaching competence of their faculty. At KTH, less attention is devoted to teaching, and the opportunity of integrated evaluations to address the teaching-research nexus was lost. But our comparison also raises questions about who is perceived as legitimate to evaluate teaching qualifications. We see that KTH uses experts who are likely selected based on their own scientific reputation to also evaluate teaching. Their academic status is apparently considered more important than their actual ability to evaluate teaching merits. In contrast, the Swedish pedagogical experts appointed by Chalmers have, as a group, lower academic standing than the experts making the scientific evaluation. We think that the legitimacy of the pedagogical experts depends not only on their effectiveness as evaluators, but also on the legitimacy of the discourse that they are seen to represent. We suggest that the discourse is more legitimate when: it is open for diversity in the conceptualisation of teaching and teaching competence; it is not confined to an “in” group who speak the right jargon and refer to a specific literature; and when portfolio production and evaluation does not deviate too far from what is seen as actual teaching competence. In the long run, however, the ideal is that professors within the applicants’ subject fields are competent to evaluate both scientific and pedagogical merits. This could help keep teaching and research together, and award status to both.

References


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Creating Gender Inclusive Engineering and Science Classes – Establishing Baseline Experiences, Perceptions and Practices

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Abstract: This paper presents the initial stages of a research project aimed at enhancing gender inclusivity in engineering and science classes. Using a dual approach of ‘studying up’ and ‘studying down’ baseline data of students’ experiences and perceptions and practices of teaching staff relating to gender inclusion in teamwork was established. Four elements of teamwork in which educators can influence the inclusion of student teamwork: team formation, team roles, team facilitation, and student experiences, and assessment and evaluation, identified by Beddoes & Panther (2017, 2018), provide a framework for data collection and analysis. Student experiences were collected through survey and focus group discussion. Semi-structured interviews explored teaching staff perspectives. Analysis highlights an incongruity between students’ gendered experience of teamwork and staff perceptions. The findings contribute to the understanding of gendered dynamics with engineering and science classes.

Introduction

Teamwork is critical to the success of engineering projects. Consequently, accreditation criteria for engineering programs generally include an expectation that graduates are able to work in teams. For example, the fifth student outcome listed by the ABET Engineering Accreditation Commission (2018, p. 6) is “an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives”. Furthermore teamwork is now frequently used in engineering to provide interactive, problem, and project-based learning opportunities.

To society’s detriment, the potential of and opportunities for women in engineering continue to be unmet (Ihsen & Buschmeyer, 2007). Many researchers have found evidence of non-inclusive interactions in engineering practice (Clerc & Kels, 2013; Faulkner, 2009; Gill, Sharp, Mills, & Franzway, 2008; Hatmaker, 2013). For example, female engineers often find that: their work and their recommendations are under-valued by team-members, they are seen as women before being engineers; and colleagues make assumptions about their capabilities and allocate roles and opportunities based on the sex. Similarly, gender non-inclusive cultures have been observed in engineering faculties (Godfrey & Parker, 2010; Tonso, 2007).

Engineering educators should provide students with the opportunity to develop capabilities for the reality of gendered workplaces, and to become leaders who improve practice. This opportunity should be provided equitably – in inclusive student teams. Beddoes and Panther (2018) found that many engineering educators are ill-prepared to address these responsibilities when managing student teamwork. If student teamwork is non-inclusive then female engineering students are likely to be disadvantaged in their studies and students will
not learn how to work inclusively. The impact for female students, all graduates, the profession and society are likely to be unfavourable. In this paper we describe the initial stages of a research project in process that investigates the gender inclusion of student teamwork.

Theoretical Framework

We define a gender-inclusive student teamwork experience as one in which female and male members experience equal opportunities to contribute to the team, and to learn. We assume, based on the wealth of literature noted above, that the engineering and computer science faculty in which this study was undertaken is an example of a gendered organization as defined by Acker (1990), namely an organization in which a gendered hierarchy of status for activities, roles, and traits is reinforced through symbols, policies, interactions, and individual practices. That is, stereotypically masculine activities, traits, and roles are privileged of their feminine counterparts. Culture is often invisible to those for whom it is familiar (Ihsen, 2005). We expected that many academics and engineering students in the faculty were unaware of the gendered nature of the faculty.

Beddoes and Panther (2017, 2018) identified four elements of teamwork in which educators can influence the inclusion of student teamwork: team formation, team roles, team facilitation and student experiences, and assessment and evaluation. These elements provide a framework for the study.

Research Question

This study addresses the question “What are educator’s intentions and practices, and students’ experiences with respect to gender inclusion in engineering and computer science student teams in an Australian research-intensive university?”

Methodological Approach

A combination of ‘studying up’ and ‘studying down’ methodologies was adopted for this project. Recent studies investigating the gendered nature of engineering education have recognised the need to shift the attitude of inquiry away from one of problematisation and reform of women (Beddoes, 2017). ‘Studying up’ or studying those in who are in positions of higher social status and power shifts the focus away from those in the minority to examine the structures and institutions that govern the problem (Beddoes & Panther, 2018).

To fulfill the broader aims of this research, an approach that captured the views of those involved in facilitating and performing teamwork in engineering and science classes was required. The dual approach of ‘studying up’ and ‘studying down’ established the baseline with regards to students’ current experience of teamwork and the current practices and perceptions of teaching staff relating to inclusion in engineering and science teamwork activities, in the specific context of a research-intensive university in Western Australia.

Baseline data collection using a mixed methods convergent triangulation approach (Borrego, Douglas, & Amelink, 2009; Creswell & Poth, 2017; Fetters, Curry, & Creswell, 2013) commenced in November 2018 and is ongoing. Students’ experiences of teamwork were collected using an on-line survey in conjunction with a focus group discussion in late 2018. Interviews to capture the current practices and perceptions of teaching staff with regards to gender inclusivity in their student teamwork were conducted at the end of 2018 and in early 2019.

Participants

The participants in this research were students and teaching staff in engineering and computer science within a research-intensive university in Australia. Students were currently completing or had recently completed a unit of study in engineering or computer science that
included teamwork-centred activities. Academic teaching staff were those identified as being unit coordinators and facilitators of engineering or computing units that involve teamwork.

**Students**

Consistent with ethics approval, students were invited by email issued through the through the faculty Learning Management System (LMS), and through faculty social media to participate in a survey and/or focus group. The survey was administered on-line using the Qualtrics™ platform and was open for three weeks in late-2018. Students who completed the survey were invited to participate in a $100 voucher draw. This draw was entered separately from the questionnaire to maintain anonymity.

Survey responses were received from 119 students. Forty one were excluded because they were incomplete, leaving 78 responses suitable for analysis. Of the 78 respondents, 64% were male (n=50), 33% were female (n=26) and two students did not report or preferred not report their gender. The respondents represented a variety of units of study within a range of engineering disciplines, and included students undertaking undergraduate (n=45, 58%) and postgraduate (n=33, 42%) coursework study. Respondents were aged between 18 and 54 years (M = 22.45, SD = 5.46). The sample was highly international, with 13% of respondents enrolled as international students, 40% of respondents identifying as having a nationality other than Australian, and 22% of respondents speaking a language other than English at home.

In addition to the on-line survey, students were invited to participate in a focus group to share their experiences of work in teams within engineering and computer science classes. A reimbursement valued at $20 was offered to focus group participants. Five students indicated that they would be interested in participating and three students attended the focus group discussion. The group was comprised of all male students, aged between 21 and 23 (M = 22, SD = 1). To protect the identity of the small number of students participating in this activity, further demographic details are not reported.

Low student engagement with the focus group is attributed to the timing of the activity which was conducted after the conclusion of the university semester exam period in late-2018. A further focus group has been planned.

**Teaching staff**

Semi-structured interviews were conducted with teaching staff. Recruitment of teaching staff was achieved through criterion sampling (Miles & Huberman, 1994). Teaching staff identified as having coordinator responsibility for a unit within the engineering curriculum that involve teamwork were approached by the lead researcher and invited to participate in interview via personalised email. Three interviews have been conducted and interviews are ongoing. To date, interview participants have been male, holding full professorial status, and performing teaching across a range of engineering disciplines. Future interviews are scheduled with female teaching staff.

**Data Collection**

**Survey**

The questionnaire design was informed by previous research on gender and teamwork in engineering education and inclusive cultures in engineering practice, primarily Beddoes and Panther (2017, 2018) and Royal Academy of Engineering (2018). The questionnaire was structured around four aspects of teamwork identified as potential sites for gender bias by Beddoes and Panther (2017, 2018). Survey questions were developed through translation of lines of inquiry from Beddoes and Panther (2017, 2018) and Royal Academy of Engineering (2018), to the context of teamwork in engineering studies and to an engineering student audience. The questionnaire was tested by three engineering students known to the lead researcher and refined before on-line release.
Students provided demographic data, and then recorded their experiences of inclusivity in teamwork within a unit nominated by them from those they had studied in 2018, through a mix of open and closed questions. The survey comprised 35 questions. Nine items related to team formation, including four items that focused on team roles. The majority of items explored aspects of students’ experiences of teamwork and their perceptions and feelings of inclusion. A final four items related to teamwork assessment and evaluation. Table 1 presents examples of survey items and available responses.

<table>
<thead>
<tr>
<th>Area</th>
<th>Source</th>
<th>Survey item (Available responses)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Team Formation</td>
<td>Beddoes &amp; Panther (2018)</td>
<td>How did you form your team? (Self-formed, Assigned by tutor/facilitator, Other (please specify))</td>
</tr>
<tr>
<td>Team Roles</td>
<td>Beddoes &amp; Panther (2018)</td>
<td>What role did you take in your team? (Team leader / team manager, Technical / hand-on role, Administrator / note taker, Other (please specify))</td>
</tr>
<tr>
<td>Teamwork Experience</td>
<td>Royal Academy of Engineering (2018)</td>
<td>I am treated with respect by my team members. (None of the time, some of the time, most of the time, all of the time)</td>
</tr>
<tr>
<td>Assessment / Evaluation</td>
<td>Beddoes &amp; Panther (2017)</td>
<td>I feel that my gender impacted the assessment of my performance as part of a team. (Yes, No, Other (please specify))</td>
</tr>
</tbody>
</table>

Focus Group

The focus group discussion exploring students’ experiences of inclusivity in teamwork was conducted by a member of the research team and lasted for 90 minutes. The focus group discussion was structured around the four areas of teamwork identified by Beddoes and Panther (2017, 2018). With consent, the discussion was audio-recorded and transcribed.

Interviews

Semi-structured interviews were conducted by a research team member employed at the university, but not involved in teaching units that were team-work focused. All interviews were face to face and lasted 30 to 50 minutes. With participant consent, interviews were audio-recorded and transcribed. The interview protocol was adapted from that used by Beddoes and Panther (2017, 2018).

Analysis

At the preliminary stage, descriptive analysis of quantitative data was performed to identify the baseline by gender for students’ reported experiences of the teamwork.

Qualitative data from responses to open questions within the survey, students’ responses to the focus group discussion and interview transcripts from interviews with teaching staff were analysed using the four locations of gendered team work identified by Beddoes and Panther (2017, 2018) as an analysis framework. Each qualitative data source was analysed separately. Transcripts and statements were deductively coded using these categories as a priori codes. Responses within these categories were then analysed using an inductive and interpretive approach, involving in-category coding and clustering into themes (Creswell & Poth, 2017). NVivo software was used to assist with qualitative data analysis.

Qualitative and quantitative data were integrated during analysis. Analysis of each data source was compared providing depth and dimension to the findings.
Findings and Discussion

Findings relevant to the research question are presented below. A synthesis of analysis of the three data sources of data are presented, following a weaving narrative approach (Fetters et al., 2013). Key themes are described and areas requiring further investigation are highlighted.

Team Formation

The key findings related to team formation are that i) teams are commonly formed by teaching staff and ii) gender composition is rarely a consideration when forming student teams.

The majority of students were assigned to their teams by teaching staff (staff-assigned \( n = 47, 60\% \) of survey respondents; self-formed \( n = 23, 30\% \) of survey respondents). This result was echoed by focus group participants who all worked in teams formed by their unit-coordinator or facilitator.

Teaching staff reported drawing on a wide range of strategies when forming student teams. These ranged from objective strategies designed to avoid biases, to random allocation of students to teams, to allowing students to forming their own teams. One professor explained:

\[
\text{I use WAM [weighted average mark], totally objective, and nobody can say oh, you're biased towards gender, towards race, culture. [Male professor 3]}
\]

Consistent with Beddoes and Panther (2018), gender was not often considered during team formation. For students who self-formed teams, two of the 23 survey respondents considered gender composition during team formation. The most common considerations when self-forming a team included i) choosing to work with friends (\( n = 13, 56\% \) of respondents in self-formed teams, 17% of total sample) and choosing to work with people that they feel comfortable with (\( n = 12, 52\% \) of respondents in self-formed teams, 15% of total sample). Similar experiences were noted in the focus group.

These findings are consistent with previous research indicating that self-forming teams are likely to consist of members who are familiar with each other (Beddoes & Panther, 2018). Self-forming teams may be homogenous, risking creative performance (Hoever, van Knippenberg, van Ginkel, & Barkema, 2012) and, in the engineering context, reducing design outcomes (Menold & Jablokow, 2019).

For staff, English-language ability was perceived to be a more significant factor than gender in team formation, and was perhaps easier to factor in when forming student teams. One interview participant indicated that he did consider gender when forming groups, but that low numbers of female students in his unit made this difficult to reconcile.

\[
\text{Once you, I start playing oh, I'd better have one woman in each group its already impossible. The numbers just don't work out. My last unit I had one student out of 12 who English was their first language so most of the teams don't have an English speaker. Nothing I can do about that. [Male professor 1]}
\]

Focus group discussions provided a contrasting example of the consideration of gender in team formation. Two of three focus group participants worked in teams of all male students, while female students were placed together in teams by their facilitator. When asked about this practice, the students viewed this as a good practice as a solo female in a group may feel out of place, intimidated or groups may be unbalanced.

The preliminary findings reflect the contested nature of recommended practice regarding gender and team formation (Beddoes & Panther, 2018; Mills, Ayre, & Gill, 2010). Students and teaching staff have a level of awareness of the individual characteristics of students, but
gender is not be viewed as a priority, or may be perceived as a difficult characteristic and is given inconsistent consideration. Additional data from teaching staff is necessary to further explore these perceptions and practices.

**Team Roles**
The key findings related to team roles were that: i) the team roles occupied by students were gender segregated, ii) role choice was driven by aligning with strengths and prior experience, iii) female students were less likely to feel free to choose a role of their liking, and iv) roles were infrequently assigned to students by teaching staff.

The most common team roles identified by survey respondents were a ‘technical / hands-on’ role \((n = 26, 33\% \text{ of respondents})\) or a ‘team leader / team manager’ role \((n = 20, 26\% \text{ of respondents})\). Fifteen per cent of survey respondents indicated that they occupied a blended role, or performed several roles over the course of their teamwork activity.

Gender segregation of team roles was evident (Figure 1). Male respondents were most likely to occupy a ‘technical hands-on’ role \((n = 20, 77\% \text{ of ‘technical/hands on’ respondents})\) while female respondents were more likely to work in a ‘Team Leader/Manager’ role \((n = 9, 35\% \text{ of female respondents, 45\% of ‘team leader/team manager’ respondents})\) or an ‘Administrative/Note Taker’ role \((n = 8, 31\% \text{ of female respondents, 57\% of ‘administrator/note taker’ respondents})\). These findings are consistent with research identifying that women self-select into or are relegated to roles that are stereotypically feminine and less valued, such as note taker or organizer (Beddoes & Panther, 2018; Hatmaker, 2012; Meadows & Sekaquaptewa, 2013).

Respondents chose roles that they felt aligned with their perceived strengths and prior experience. Others felt compelled to take on a certain role within a team to achieve desired outcomes because “no one else would”. Several respondents indicated that as local students or native English speakers, they felt pressured to do this.

84\% of male respondents \((n=42)\) indicated that they were free to choose the role that they wanted within their team. Female respondents indicated constrained role choice, with 34\% of female respondents disagreeing that they were free to choose their role, as compared to 8\% of male respondents. One survey respondent described the source of her constraint:

*The team consisted of two alpha male engineering students (as I like to call them). The sort of people who consider themselves the best in the*
team and most opinionated, so they out spoke me [Survey respondent, female 5th year MPE student]

When asked if they felt excluded from ‘technical/hands on’ roles, most students indicated that they did not. However, written statements from some female respondents are contradictory:

The guys thought I couldn’t code because I was a girl, and let me only do the writing tasks. [Survey respondent, female 3rd year BSc student]

The apparent tension between these results and the feelings of constraint regarding role choice indicated by female respondents warrant further investigation.

Teaching staff did not commonly assign team roles. Only two survey respondents indicated that they were assigned roles within their team by staff, or did not have a choice over the role. As with team formation, gender was not considered by teaching staff nor explicitly addressed in the guidance provided to students in assigning team roles. Again, these findings align with those of Beddoes and Panther (2018), who noted that professors rarely address team roles when forming teams.

Experience of Teamwork

The key findings relating to the experience of working in a team are i) female respondents were less likely to report inclusion and respect by team members, ii) there were minimal instances of experiencing or witnessing bullying or harassment, iii) key challenges related to inequitable workload and team member quality, and iv) English language ability, rather than gender being viewed as a key factor by teaching staff.

Students’ experiences of teamwork were generally positive. Female students were less likely to report feelings of inclusion, respect and being heard by team members, consistent with other studies in universities and the workplace (Hatmaker, 2012; Tonso, 2007). A statement from one female respondent illuminates this finding:

My knowledge was belittled, and my opinions were disregarded. [Survey respondent, female 3rd year BSc student]

There were few instances of survey respondents having experienced or witnessed bullying (n = 3) or harassment (n = 1). The cases were reported by female respondents, and the majority related to conflicts or disputes between team members rather than personal experience.

Despite these indications, most respondents perceived their gender to be irrelevant to their teamwork experience. 80% of male respondents and 53% of female respondents indicating that their gender was irrelevant to how they were perceived by team members. Student sentiments ranged from ambivalence to ignorance:

Most people our age don’t care what gender you are, as long as you are a nice person, you’re fine. [Survey respondent, male 3rd year BSc student]

I don’t know how it could impact my experience? [Survey respondent, male 5th year MPE student]

Female respondents described both positive and negative impacts of their gender on their teamwork experience. Negative perceptions were related to being overlooked, skills negated or being treated differently. Positive perceptions were associated with skills such as ability to organise, neatness, attention to detail and ability to bring a different perspective to the group. Within the engineering context such behaviours are typically devalued in comparison to technical contributions (McIlwee & Robinson, 1992). Skills such as neatness are stereotypically feminine attributes and marginalized in a gendered environment.
In contrast to the generally positive student experience, teaching staff perceived that students often find teamwork activities and assessments challenging. Staff had varied perspectives on the significance of gender and students’ experiences of teamwork. One professor stated that students had never raised gender as an issue. Another described encountering problems related to gender, specifically in randomly assigned teams:

*Maybe two or three times that was a female student in a group of students and she’s very simply saying that they have different opinion than the rest of the team and simply their opinions seem to be disregarded… [Male professor 2]*

Consistent with their experience and practices relating to team formation, teaching staff considered English-language ability to be a more significant factor than gender in impacting students’ experience of teamwork.

**Teamwork Evaluation and Assessment**

The key findings relating to teamwork evaluation and assessment were i) assessments are generally perceived to be fair, ii) students described uneven and unfair workloads, often related to poor contribution by other students, and iii) gender was not considered to be an influence upon assessment.

In general, students indicated that they felt that they had been fairly assessed by teaching staff \((n = 53, 62\%\) of respondents) and peers \((n = 48, 68\%\) of respondents). However, students did report some dissatisfaction with the fair allocation of work in their team-work centered activities, with 35\% of respondents disagreeing or strongly disagreeing with the statement ‘Work was allocated fairly within my team’. A higher proportion of female students expressed dissatisfaction with workload allocation.

Survey text responses attribute this to the poor quality of team members, and issues related to lack of English fluency and communication ability. These sentiments were echoed in the focus group, in which workload was keenly discussed:

*We tried to divide the workload up evenly but, people just don’t really do work, so you have to do the work because it has to get done. [Focus group 1 participant, male 3\textsuperscript{rd} year BSc student]*

This is consistent with the discussion relating to motivations for team role choice. Further analysis is required to determine if there are relationships between workload allocation fairness and enrolment type, language spoken at home, team roles and gender. Results suggest that despite uneven or unfair workloads, and gender segregation of roles, the assessment of or reward for extra work was accounted for in evaluation.

**Recommendations, Implications and Future Research Plans**

The preliminary findings support the presence of gendered teamwork experience in engineering and science classes, and an incongruity with perceptions of teaching staff. Little attention is paid to gender and the impact of international students’ English-language ability is viewed as more significant to many students and teaching staff. The findings suggest that staff do need support to facilitate gender-inclusive teamwork, beginning with awareness and addressing beliefs, supporting Beddoes & Panther (2017).

This paper reflects a research project in progress. Further data collection is planned to enhance the baseline data and to allow exploration of areas that have emerged as warranting further investigation. Statistical testing of collected data will be performed and reported in future publications. Combined with extant research, this will inform the development of evidence-based resources for teaching staff. As the project continues,
resources will be delivered to teaching staff through a training workshop and the impact of the training workshop will be evaluated through reassessment of student experience and staff practices.

References


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Engineering students’ perceptions of the learning experience and its impact on student success

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Abstract: Effective educational practices include a focus on learning, and define clear pathways to student success. Initiatives are in place in most post-secondary institutions to ensure student retention and graduation, but research shows that success strategies may not make their way into the classroom. This qualitative study explores what students believe contributes to, or impedes, their learning experiences. Engineering students completed an online Stop, Start, Continue survey, and thematic analysis identified four themes related to student success: classroom practices, supporting resources, quality of teaching, and academic support. Students report that classes are mostly lecture-based. Coded items indicate students use surface learning approaches to survive, and that cognitive overload may occur during class. Students want to be taught relevant content by respectful, caring instructors, and be meaningfully engaged in their learning. Engineering educators can use these insights to create learning environments that support student success.

Introduction

A poem was penned on the window in an undergraduate engineering lounge just before the start of a new term: “I am a little engg student angry and depressed. Here is my homework and here is a test. When I get my grade back hear me shout, Screw me over I’m failing out.”

It is difficult to say how the student got to this state, but it suggests a learning environment that is less than conducive to this student’s academic success.

Student success initiatives are in place in most post-secondary institutions to ensure student retention and graduation. Myriad models for student success exist in the literature, but as van den Bogaard (2012) reports in her synthesis of literature on student success related to engineering education "many of the studies are based on retrospective quantitative analyses and miss data on the student’s perceptions of the educational environment and their well-being". Insights into student success can be enriched by allowing students to identify and contribute what they believe might improve their engagement and chances of success in their chosen programs. This paper examines the results of a qualitative study of undergraduate engineering students’ perceptions about their learning experience through the lens of student success.

Background

It is said that “student learning is central to student success and … without learning, students are not successful regardless of whether or not they persist. The more that students learn and value their learning, the more likely they are to stay and graduate” (Tinto & Pusser, 2006). This section examines the literature on student success, effective learning environments, and the opportunities students have to reflect on their learning experiences.

Academic and Student Success

An analytic literature review identified six components of academic success: (1) academic achievement, (2) satisfaction, (3) acquisition of skills and competencies, (4) persistence, (5)
attainment of learning objectives, and (6) career success (York, Gibson, & Rankin, 2015). Institutions commonly measure academic success through academic achievement and student satisfaction. Grades and grade point averages (GPA) are readily available, and most institutions annually receive feedback on student satisfaction. Course-based assessments such as exams, assignments, and labs are often used to measure the acquisition of skills and competencies. Program-level learning outcomes can be demonstrated in capstone or culminating senior year projects, and through exemplars gathered for accreditation purposes. Persistence is measured in retention rates, especially from first to second year of a program, and in graduation rates. Career success includes a number of factors such as job attainment rates, career satisfaction, starting salary, and opportunities for advancement. Together these six components provide a rich and generalizable way for institutions to measure overall student success.

Most higher education institutions allocate significant resources to facilitate student success. Unfortunately these efforts are not always productive. There is often a disconnect between student support services and what is happening in the classroom (Tinto, 2012). This may, in part, be caused by a differing definition of success between student support services whose overarching goal is academic success as defined by York and his team, and academic staff at the program level and in the classroom whose goal is the success of individual students. This becomes apparent in systematic literature reviews that focus more specifically on student success in the undergraduate engineering classroom (Boles & Whelan, 2017) (van den Bogaard, 2012). Collectively they identify educational climate, student interests, student behaviour, and external factors (funding, personal situations, etc.) as the four components of student success. Educational climate includes six aspects: (1) the learning environment, (2) the quality of interactions between students, their instructors and the context, (3) the design and organization of the curriculum, (4) assessments and feedback, (5) learning supports, and (6) the campus environment. Student interest encompasses students' perception of themselves as students, their ability to self-regulate, their academic capability, and the way they handle workload. Student behaviour includes preference for individual or collaborative learning, the effort and time allocated for academic tasks, and influences from their background and disposition. Of these four components, educational climate and more specifically the learning environment are identified as the key factors in the student success. Responsibility for that success should be shared between the students in the ways they engage with their learning, and their educators in creating effective learning environments.

Effective Learning Environments

Research conducted at tertiary institutions that consistently perform well in graduation rates and student engagement (as measured through national student engagement surveys) (Kuh, Kinzie, Schuh, & Whitt, 2005) (Coates & McCormick, 2014) shows that when learning is prioritized, and appropriate physical, human and training resources are allocated to the process, students can and will be successful. These institutions exhibit four effective practices. They (1) provide academic challenge, (2) use active and collaborative learning techniques, (3) have higher levels of faculty-student interaction, and (4) feature high quality student relationships with other students, faculty, and staff.

In addition to this work, myriad benchmarks exist to define and measure effective learning environments (National Survey of Student Engagement, 2018) (Quality Indicators for Learning and Teaching, 2017) (UNISTATS, 2018) (Stupnisky, BrckaLorenz, Yuhas, & Guay, 2018) (Tinto, 2012). Six themes emerge from these benchmarks: (1) academic rigour, (2) a focus on learning, (3) supported instruction, (4) quality of teaching, (5) relationships, and (6) student engagement. Academic rigour can be defined as the intersection of meaningful content, active learning, expectation, and higher order thinking (Draeger, del Prado Hill, Hunter, & Mahler, 2013). Expectations must be clear and consistent for students to be successful (Tinto, 2012) and there must be opportunity for students to meaningfully engage with the content. Students should be involved in, and with, their learning through active,
collaborative, reflective, and integrated learning (Freeman et al., 2014). Higher order learning, development of skills, and quantitative reasoning should also be emphasized.

Supported instruction encompasses the teaching and learning efforts that are done for the students both in and beyond the classroom. It includes learning resources that support those opportunities, and the associated assessments and feedback. These are closely related to aspects of teaching quality which encompass effective teaching practices, and instructional clarity of the instructor. Good working relationships between students, their peers, faculty, and the staff all contribute to an effective learning environment. Finally, student engagement includes the time and effort students put in that contribute to their success, and the ways in which an institution encourages and supports student success.

Student Voice

The student voice is important in establishing an effective learning environment and helping ensure student success (Harvey, 1999). Student evaluations of teaching (SET) are a common method used for gathering feedback about the students' learning experience. This form of summative evaluation generally serves three purposes: (1) improving teaching quality, (2) providing input for appraisal and promotion purposes, and (3) providing evidence for institutional accountability (e.g. demonstrating the presence of adequate procedures for ensuring teaching quality (Spooren, Brockx, & Mortelmans, 2013). Unfortunately the overall educational experience doesn’t necessarily improve with SETs, especially when they are used in isolation (Brookfield, 2017). Individual instructors and their supervisors are often the only people who see the results of SETs, and then only after the course is over. The students themselves rarely benefit from the feedback they provide. Value can be added when the course delivery responds to formative feedback gathered during the course.

Institutions and departments may also receive student feedback from annual national student engagement surveys. The most widely recognized surveys, NSSE (National Survey of Student Engagement, 2018), QILT (Quality Indicators for Learning and Teaching, 2017), and NSS (UNISTATS, 2018) measure student engagement using common benchmarks including academic rigour, learning experiences, supported instruction, quality of teaching, and the ability of students to establish positive academic relationships. It is informative to compare institutional and departmental data with both the national results and results from other disciplines. These studies show that in the last few years engineering students appear to be less engaged than their peers in almost all other disciplines (National Survey of Student Engagement, 2018) It would seem that the undergraduate engineering learning environment is not as effective as it could be.

Unfortunately SETs and student engagement surveys are based on what administrators and educators think is important to the student experience (Harvey, 1999) and miss data on the students’ perceptions of their learning environment (van den Bogaard, 2012). In order to understand what students perceive as useful for their own success they must be given the opportunity to identify and raise issues that are important to them.

Boles and Whelan (2017) did such a study, using focus groups to examine the barriers to student success in engineering education. They report two key findings: (1) student success requires students to be actively engaged in their learning, and (2) the student experience and student success is significantly impacted by the quality of the interactions between teachers and students both in and beyond the classroom.

This paper seeks to extend that research by exploring what undergraduate engineering students believe contributes to, or impedes, their learning experience. It asks the following:

1. What do students want ‘started’, ‘stopped’ and ‘continued’ in their classes?
2. What aspects of the existing undergraduate engineering learning environment contribute to or impede student success?
3. What strategies can engineering educators implement to enhance student success?
Methodology

All 3187 full- and part-time undergraduate engineering students attending a mid-size Canadian engineering school received an e-mail inviting them to complete an online survey entitled ‘A Snapshot of Canadian Engineering Education: What Do Engineering Students Think about their Classroom Experiences’. The survey was sent at the beginning of the winter semester and there were no incentives provided for completing the survey.

The survey was modeled on the ‘Stop, Start, Continue’ method that is often used for gathering qualitative feedback from students in higher education (Hoon, Oliver, Szpakowska, & Newton, 2015) (George & Cowan, 1999). The snapshot survey was divided into two main sections: (1) Basic Information, and (2) Thoughts about your Undergraduate Engineering Classes. The ‘Basic Information’ section gathered demographics, while the ‘Thoughts’ section contained six questions related to their classroom experiences. The first three questions asked students to identify what they would like their instructors to start (“List things that your professors or instructors might start doing in class that you would find helpful”), stop ("List things you wish your professors or instructors would stop doing in class because they are not helpful") and continue doing ("List things that your professors or instructors should keep doing in class because you find them helpful"). The next two questions asked students to describe their best and worst experiences in the classroom. The final question asked them to identify how they feel engineering classes helped or hindered their learning. Only the Start, Stop, and Continue responses are considered in this analysis.

The University of Calgary Conjoint Faculties Ethics Board approved this research study.

Data Analysis

262 of the 3187 engineering students participated in this research study (8.2%). Of the 262 respondents, 100 chose not to answer any questions beyond the Basic Information section. The demographics of those non-responders are excluded from the following breakdown.

46.4% of respondents were female and 51.0% male. For other gender-related responses, there were insufficient numbers to ensure anonymity. This distribution is not representative of the gender breakdown within the school (25.5% female, 74.5% male). 31.8% of respondents indicated they were registered in first year, 21.9% in second year, 23.8% in third year, 13.2% in fourth year, and 9.3% in fifth year having returned to their studies after an internship. 3.3% of the respondents were international students.

Deductive thematic analysis was used to code the student responses. Theory triangulation ensured the validity of the categorizations, with the codes resulting from this analysis being very similar to those coded using the benchmarks employed in student engagement surveys, and the elements of curriculum defined within the Universal Design for Learning (Meyer, Rose, & Gordon, 2014). 441 items were coded from the Start responses, 313 from the Stop responses, and 395 from the Continue responses.

Initial coding analysis produced 16 open codes for student responses (e.g. direct instruction, resources, presentation methods, evaluation, etc.). These 16 open codes were then recoded to form four definitional categories based on the components of student success: (1) learning environment, (2) personal traits, (3) student behaviour, and (4) external factors.

Results

This section reports on the perceptions of the students who participated in this study. It reflects aspects of the current undergraduate engineering learning environment that contribute to, or impede, student success.

Current Helpful Practices – ‘Continue Doing’

Three primary themes emerged from the responses to the “Continue Doing” survey question: (1) classroom practices, (2) resources used to support lectures, and (3) the instructor.
Students generally describe their classes as mostly traditional and lecture-based. Responses show they value lectures that are well organized, have a logical flow, and relate new concepts to those they've already learned. They appreciate instructors who handwrite their notes using a document camera or board instead of speaking to slides. Students want their instructors to continue providing many and varied examples in class, particularly those that are relevant and applicable in the real world. They want continued opportunities to practice what they are learning, recognizing it is “truly helpful to tackle a problem with the professor as he/she explains the thinking process for each step.”

Students want faculty to continue to post slides and notes, preferably before class so they can be used while new content is being covered. They appreciate slides that are clear and well organized, but don't contain too much information. They like it when visuals and models are used to explain concepts, and appreciate videos they can access outside of class. Students want instructors to continue to post slides and notes, preferably before class so they can be used while new content is being covered. They appreciate slides that are clear and well organized, but don't contain too much information. They like it when visuals and models are used to explain concepts, and appreciate videos they can access outside of class.

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Students value their time and feel it is often wasted in classes where instructors go off topic, ramble, or rant about unrelated matters. Students would also like instructors to stop coming to class disorganized and/or unprepared. They do not appreciate instructors who are condescending, or treat students or other instructors with disrespect.

Current Unhelpful Practices – ‘Stop Doing’

Two themes emerged from the responses to the “Stop Doing” survey question: (1) classroom practices, and (2) the instructor.

Many students identified that it is often difficult for them to keep up in class. They would like instructors to stop talking “non-stop” for the whole class, reading directly from slides, and embellishing or going too deep into a topic too soon. They also ask that instructors don't overlook the small steps in their explanations and worked examples. What is easy and taken for granted by the instructor, is still new and challenging for many students. Students do not appreciate it when they are not given time to process what is being taught, nor do they like it when instructors refuse to answer their questions either in or outside the classroom. Students want instructors to stop assuming students understand the concepts “just because no one asks a question” or “because they have "taught" it”.

Students do not particularly like prepared slide presentations, indicating that they are considered information dumps. They also claim they don't really process what they are learning during slide-based classes. Nor do they see much value in technology-based active learning platforms designed to motivate students to attend and engage them in their learning.

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Desired Practices – ‘Start Doing’

Three themes emerged from the responses to the “Start Doing: survey question: (1) classroom practices, (2) academic support, and (3) resources used to support the lecture.

Students reiterated the desire to have instructors handwrite presented materials. They feel it controls the pace of the class, giving them time to think about what's being presented and making it easier for them to follow the flow of ideas. They would like instructors to cover key concepts in more than one way, and to clearly identify which topics and concepts are most important and “what it all means in a real-world situation”.

Students highly value both example and practice problems. They would like instructors to consistently explain their thought process, especially when solving complex worked
problems. They would like instructors to challenge them with increasingly difficult examples and problems so that students are prepared for their exams.

Students value the support they get both in and beyond the classroom. Students would like instructors to start using different methods and approaches to help them better visualize and understand concepts. They appreciate instructors who encourage questions, provide reviews of requisite prior knowledge, and repeat key concepts. They would also like instructors to recognize when students lose focus and allow time to “absorb and discuss any questions”.

Students also reiterated the desire to have clear, concise, detailed notes or slides posted before class. They would like instructors to post all required and supplementary resources in an easily accessible and organized way.

Through the Lens of Student Success

Four themes emerged from the student responses when examining the Start, Stop, and Continue responses through the lens of student success: (1) classroom practices, (2) instructional strategies, (3) assessments, and (4) shared responsibility.

Almost half (48.0%) of the coded items indicate that the current undergraduate engineering learning environment is traditional with teacher-directed classes. Students seem to accept lecture-based delivery as part of the culture of undergraduate engineering education. That does not, however, mean that all students perceive value in lectures, at least not in the way many are currently delivered. Comments like “I find when courses are based on power point slides, especially when introducing new topics, its very difficult to learn or understand anything”, and “I found powerpoint-style lectures to be very unhelpful in engineering” suggest that other instructional strategies and methods may be more helpful. Students see value in covering important topics in more than one way and would like “an explanation of why we are required to learn the content, why it is important, and how it can be useful”. Students clearly enunciate the desire for lectures to be supported by worked examples.

A number of coded items relate to instructional strategies that, while they are teacher-directed, encourage students to discuss, observe, investigate, draw inferences, and solve problems. Students value different methods of “dissecting a problem to get to the important details” and appreciate instructors who bring “physical materials, models, or demonstrations to enforce what we’re learning”. Students also indicate that practice and review problems are crucial to their success, as shown in comments like “I feel that having more practice would help me remember the concepts we learn in the long run”. Each of these strategies involves active learning, a key element of student success.

A number of coded items focus on assessments. Students believe formative assessments such as assignments and quizzes are useful as expressed in “using frequent low-consequence quizzes to encourage students to stay on top of things”. Many assessment-related comments implied the need for surviving versus actually learning. Comments such as “sometimes you don’t need to waste a whole class on something that won’t be tested on the final” and “It may feel like explaining everything about a concept is helpful, in reality forgoing crucial time on the parts that we need to know for exams or assignments is hurting our understanding” suggest that some students are more concerned about passing than they are about learning. This approach, called surface learning, is a common coping strategy where students routinely memorize facts and procedures in order to reproduce content (Entwistle & Peterson, 2004). It often causes learners to feel undue pressure and become anxious about their studies, neither of which is conducive to student success.

Further coded items indicate that many learners are prepared to take responsibility for their own learning, given an effective learning environment. Comments such as “Students should attend lectures because the lectures are valuable and worth attending, not because they are being forced to” show that extrinsic motivators are not necessary if there is perceived value in the classroom experience. They appreciate well organized, well-paced classes as shown in comments like “the professors did everything right: use a whiteboard for the lecture, talk at
a good pace, speak clearly, post lecture notes online, post practice problems with walkthroughs, and have clear expectations about exams. This was a hard class but that didn't matter because I enjoyed lectures and got lots out of them. "These, and myriad similar comments, show students' readiness to learn in a traditional teacher-centred classroom.

Discussion

This study explored what undergraduate engineering students believe contributes to, and impedes, their learning experience. It provides the missing data on the students' perceptions of their educational environment and well-being, a need identified by van den Bogaard (2012). The data is explored through the lens of student success with the student responses highlighting four key areas:

1. Classroom practices that are teacher-directed and lecture based
2. Students' desire to be successful in their studies
3. The difference an instructor can make to the learning experience
4. Recognition that active involvement is beneficial to learning

It is clear from both the students and the literature that lecturing is very much ingrained in the “culture of teaching in higher education” (Cerbin, 2018) (Nelson & Brennan, 2018) (Freeman et al., 2014). It appears that engineering students expect to be taught, and/or have been conditioned as passive learners. Their focus on “what's on the test” suggests they may be applying surface learning approaches in order to survive the rigours of engineering programs (Entwistle & Peterson, 2004). For true student success, learning needs to happen at a deeper level. Moving from a transmission-based delivery to a more student-centred approach (Trigwell, Prosser, & Waterhouse, 1999) could help instructors establish a learning environment where student success is measured in ways that move beyond the GPA.

Many student comments implied an underlying desire to be successful in their studies. They see value in good classes and talk about wanting time to think about, absorb, practice and apply new knowledge and skills. At the same time students are quite candid about aspects of their learning environment that impede their learning. Self-determination theory as related to motivation suggests that establishing a supportive and motivating learning environment can foster students' desire to thrive (Cook & Artino, 2016) (Fowler, 2014). Students' myriad requests for examples and problems show a desire to learn, but may also indicate they are experiencing cognitive overload. Effective learning occurs when the capacity of working memory is greater than the sum of all cognitive loads (Sweller, Ayres, & Kalyuga, 2011). This overload can be managed using three classroom techniques: (1) breaking overall tasks into smaller chunks and clearly demonstrating the individual steps or elements associated with a new concept, (2) focusing on key concepts and eliminating or reducing nice-to-know information, and (3) using scaffolded learning where the application of new knowledge is practiced regularly, with each experience a little more complex than the last. Incorporating these strategies should help improve both learning and the students' ability to be successful.

It is clear from both the students and the literature that the instructor makes a difference in the learning environment. Ideal professors are characterized as those who are “highly accessible to students, allow student input into the course policies and procedures, provide for significant variety in the course, and provide a comfortable learning atmosphere for students” (Epting, Zinn, Buskist, & Buskist, 2004 p 182) and those who demonstrate presence and caring, promote learning, keep their teaching current, and are enthusiastic and passionate about teaching (Rossetti & Fox, 2009). Our students want to be taught by organized, prepared, respectful, and passionate instructors who care about student success.

Student comments show an imbalance between the number of teaching-related comments about things done “for” the student and the number of learning-focused comments about things done “by” the student. Students want to be taught relevant content and understand how the knowledge and skills they are learning are applied in authentic applications. Students also want opportunities to be actively involved in their learning. Adopting a model of
academic rigour that encourages the intersection of meaningful content, active learning, expectations, and critical thinking (Draeger et al., 2013) may help establish a balance between content and learning. In order to improve opportunities for student success, students should be encouraged to move beyond survival tactics (e.g. following pre-defined or memorized processes to get a passing grade) toward thinking critically about complex engineering systems, the integration of cross-course and cross-discipline knowledge and skills, and ultimately achieving true academic success.

Limitations

We believe that the participants in this study represent all Canadian engineering students, but recognize they are not statistically representative. The findings of this survey may have a bias associated with non-response. Those students who chose to complete the survey may have different views from those who did not. It is also not known what other factors may have contributed to response or non-response. As a result, these findings should be considered in the context of the limitations of this study.

Conclusions and Future Work

Extensive research supports myriad student success initiatives in higher education. This research adds insights from the students’ perspective that can help engineering educators create learning environments that support student success. Student views suggest that a more active and supportive student-centred learning environment would contribute positively to their overall success.

This research project lays the groundwork for a number of further studies. Examination of the success strategies practiced by undergraduate engineering students would help determine if students are sharing in the responsibility for their learning. Additional work could be done to determine the impact of implementing the student success strategies identified in this study.

It is hoped that adding this research to the existing body of evidence on student success will encourage engineering educators to establish learning environments where student success is measured in ways that move beyond the GPA.

References


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Manuscript Authors’ Perspectives on the Peer Review Process of the Journal of Engineering Education

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Abstract: Research communities often emphasize theoretical frameworks, methodologies, and topics that appeal to particular subgroups of scholars within the community. Therefore, one of the challenges associated with the peer review process is ensuring that innovative ideas are not rejected simply because they live outside the conventional paradigms of the community. Determining why manuscripts are rejected from premier outlets, which influence the norms of a field, can further our understanding of existing disciplinary boundaries and how to increase the diversity of perspectives and the participation of scholars with views outside the conventional paradigm in the community. However, much of the literature on disciplinary boundaries focuses on the reliability of reviewers themselves and published manuscripts. As such, this paper focuses on the experiences and perspectives of scholars who have submitted to but not published an article in the Journal of Engineering Education through in-depth, qualitative interviews.

Context

Academic journals are the traditional medium for sharing research findings and disseminating new knowledge within and across research communities. Academic journals serve as warehouses where the knowledge of a discipline can accumulate and develop over time. Editors and peer reviewers are charged with ensuring that published manuscripts adhere to a set of characteristics or norms agreed upon by the research community for that particular field of study. Published manuscripts, therefore, communicate disciplinary values in terms of theoretical frameworks, methodology, and topics while unpublished manuscripts provide evidence to what is not valued by that research community. Unfortunately, the peer review process can lead to homogeneity of research paradigms which fundamentally shapes the questions that are posed, how results are interpreted, and subsequently, what knowledge accumulates over time (Amsterdamska, 2005).

Engineering Education Research (EER) is an emerging, interdisciplinary field that draws on a diverse set of research paradigms from multiple disciplines such as education, psychology, and sociology. As an emerging field, EER is still forming the specific research expectations of the field and has been transitioning to focus on the importance of theory and implications beyond an individual classroom for over a decade (Baille & Bernhard, 2009; Borrego, 2007; Felder, Sheppard, & Smith, 2005; Nyamapfene & Williams, 2017). As the field develops, manuscripts published in the Journal of Engineering Education (JEE) should reflect a heterogenous set of theoretical frameworks, methodologies, and topics (Wankat, Williams, & Neto, 2014; Kloot, 2017). However, prior work has documented homogeneity of theoretical frameworks (Beddoes, Schimpf, & Pawley, 2014), an underrepresentation of qualitative...
methods (Beddoes, 2012; Borrego, Douglas, & Amelink, 2009; Douglas, Koro-Ljungberg, & Borrego, 2010), and a lack of engagement in feminist methodologies and theories (Beddoes, 2013) among other trends. Nevertheless, the extent to which the peer review process in EER has influenced and perpetuated the characteristics and boundaries of the field is unknown. As such, analysis of the peer review process at JEE can offer insights into the development of EER and expand our understanding of the theoretical, methodological, and topical boundaries of the field. This project focuses specially on the peer review experience of authors who have submitted a manuscript to the JEE that was not accepted for publication by the journal. We refer to this group as manuscript authors throughout this paper.

Research Question

This paper addresses the following research question: What do members of the EER community who have submitted to, but never published in, JEE see as the topical, methodological, and theoretical boundaries of engineering education research? The rationales of this research are: (1) that identifying the theoretical, methodological, and topical boundaries of engineering education research will facilitate a continuous dialogue around the ways that knowledge enters the field of engineering education research, and (2) such a dialogue can help advance the development of the field.

Methods

Larger study

The data analyzed for this study were pulled from a larger, on-going project aimed at exploring the field of EER through the community’s peer review experiences. JEE was selected because it is widely recognized as the premier engineering education journal (Pawley, Schimpf, & Nelson, 2016), and thus, functions as a primary gateway for new knowledge within the EER community. Participants were identified through a series of targeted surveys and contact information included in JEE’s table of contents between 2013 and 2018. A purposeful sampling approach was used to identify 35 authors representing three unique perspectives to participate in semi-structured interviews: (1) manuscript authors who have submitted and only had a manuscript rejected from JEE, (2) authors who have submitted and published a manuscript in JEE, and (3) authors who had at least one manuscript rejected and at least one published in JEE. Importantly, while manuscript authors in the first category have not published an article in JEE specifically, many of them have published articles in other academic journal outlets. The authors who were selected to participate in the larger study represent a range of theoretical, methodological, and topical perspectives and had documentation of their review process to supplement interviews. As such, data was collected through multiple sources.

Semi-structured interviews were conducted in the Fall of 2018. The interview protocol was pilot tested and refined before the interviews were conducted (Singleton & Straits, 2010). Questions included but were not limited to participants’ experiences and perspectives on the peer-review process of JEE, their perspectives on the theoretical, methodological, and topical boundaries of EER, and their experiences reviewing potential articles (see below for more detailed description of interview protocol). In the Fall of 2019, we will conduct a second round of interviews with the fields’ “gate keepers,” including associate editors, senior associate editors, and/or deputy editors of JEE. The interview protocol will be based on the findings from the author interviews and focus on editors’ beliefs regarding the findings, as well as their own perspectives on the peer reviews process, and changes they believe are needed in the field.

Participants

The sample for this study was recruited through the distribution of two screening surveys. First, a screening survey was distributed to the EER communities in Australia, the United
States, and Europe through national and international engineering educational listservs and flyers at the 2018 ASEE Annual Conference in order to identify potential participants for in-depth interviews. Sixty-two potential participants indicated that they would be willing to participate. Of those, only ten respondents were eligible to be included in the analytic sample of the current study given that the restricted nature of the sample. Two additional participants were recruited through a second, targeted screening survey which was distributed to early career engineering education faculty members across the United States. Thus, the final sample included 12 manuscript authors who had submitted and had a manuscript rejected from JEE in the last five years.

The study participants were 58% female (n = 7) and represented a mix of graduate students, postdoctoral research associates, assistant professors, and individuals holding non-tenure track faculty or staff positions in the United States and Europe (see Table 1). The majority of participants (n = 10) reported engineering education as their primary disciplinary association. One participant reported their primary disciplinary association as education and one participant reported their primary disciplinary association as engineering. Fifty percent (n = 6) of the sample indicated that they have served as a reviewer for JEE in the past.

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**Table 1: Participant Characteristics**

Data collection

All participants were interviewed individually via Zoom by the principal investigator or a trained graduate research assistant in the Fall of 2018. Each semi-structured interview lasted approximately one hour. All interviews were video recorded and transcribed for later coding. Verbal consent was obtained at the beginning of each interview. During the interview, participants were asked about their experiences submitting to JEE as well as their perspectives on the EER community’s theoretical, methodological, and topical boundaries and their experiences reviewing for JEE. Participants were asked questions about why they
choose to submit to JEE, the extent to which reviewers were consistent in their feedback, and what reviewers liked and disliked most about their paper. Questions about the theoretical, methodological, and topical boundaries of EER, however, were refined after the first three interviews to clarify the meaning of the questions and accommodate participants’ understanding. The original language prompted participants to describe the current state of the fields’ theoretical, methodological, and topical boundaries and norms as well as what, if any, changes they would make to those boundaries and norms. The revised language prompted participants to describe which theoretical frameworks and methodologies are welcome in the field of EER and which are not, as well as identify which topics are prioritized and which topics are undervalued. The revised language continued to prompt participants to consider the implications of emphasizing theoretical frameworks, methodologies, and topics as well as what changes they would like to see implemented in those areas in the future. Thus, while the language of these questions was revised, the questions were still aimed at participants’ perceptions of the boundaries of EER. Finally, participants compared their experiences as a reviewer to the reviews they received when they submitted a paper to JEE.

Data analysis
Given that this paper is a preliminary analysis with limited page allotment, we focus here on presenting the manuscript authors’ perspectives. A more critical discussion of those perspectives will be presented in subsequent journal articles.

Analysis of 12 interviews was conducted using NVivo version 12 utilizing a grounded theory coding system. An a priori coding system was not superimposed in favor of emergent themes (Strauss & Corbin, 1998). Emergent patterns were used to identify themes at two levels. At level one emergent patterns were used to identify possible theoretical, methodological, and topical boundaries and themes in participants’ peer review experiences and beliefs that were explicitly referenced in participants’ discourse. At level two emergent patterns were used to identify themes in participants’ perceptions that were not explicitly stated in participants’ discourse.

Findings
Our findings are divided into two sub-sections. The first sub-section presents two themes that emerged directly from participants’ perspectives on the peer-review process in EER and the field’s boundaries. The findings presented in the first sub-section indicate that manuscript authors: (1) perceive an unwillingness to publish qualitative methodologies, specifically, single case studies and grounded theory; and (2) experience difficulty publishing theoretical frameworks, methodologies and topics not traditionally prioritized by the field. The second sub-section presents a theme not directly identified by participants themselves and, thus, represents a different level of analysis. Specifically, the findings presented in the second sub-section indicate a need to define the differences between a theoretical framework, methodology, and topics.

Participant perspectives

**Acceptable methods.** Participants’ responses for the methodological boundaries of EER revealed three themes: (1) that participants felt quantitative methods, particularly studies with large samples, are valued and understood more than qualitative methods, (2) that participants felt both quantitative and qualitative methods are valued and welcome, but single case studies and grounded theory are undervalued and misunderstood, and (3) that participants felt there is a bias toward “rigorous” research in comparison to research conducted by practitioners in their own classrooms.

Four of the participants expressed that they felt quantitative methods are very accepted among the engineering education research community over and above qualitative methods. One participant said, “...just some statistical thing. I think they are definitely more interested in quantitative than they are in qualitative.” There was, however, some variation in the
reasons participants identified for valuing quantitative over qualitative methods. For example, one manuscript author felt that the field preferred quantitative over qualitative methods because, “…engineers need statistics and numbers to be convinced of things,” while another participant felt that:

When it comes to qualitative data, people not only aren’t as interested in the articles, but they also aren’t as familiar with the research methodology and what makes the analogs of validity and reliability in qualitative research. So, I think a lot of times, reviewers who are normally used to quantitative methods are unprepared to review articles related to qualitative methods, and then that ends up being kind of a biased. It’s like a vicious cycle of more and more quantitative articles get published and people don’t kind of raise up those qualitative ones.

The majority of participants, however, felt that while qualitative and quantitative methods are both welcome, case studies and studies utilizing grounded theory are hard to publish. For instance, one participant perceived that, “…quantitative methods are very accepted. I think that’s not a surprise. Qualitative methods are too….I don’t know if the case study would be accepted like it is in business. I’m not seeing many at all of articles of a case study.” Similarly, another participant who fell into this category of responses said that:

I do think that because a lot of us started in engineering, we’re just more comfortable with quantitative data and in analyzing it in that way. I personally haven’t felt the, ‘Oh, you haven’t produced new knowledge because you’re doing qualitative work.’ I haven’t felt that at all. I’m actually really surprised that I didn't feel that because entering the field, that was one of my big fears was that wouldn't respect me because I was doing qualitative work. People in engineering education don't-- I don't get that from them.

At a different time during the interview, however, the same participant said that, “... the only [method] that’s kind of a little weird is grounded theory because I don't think people have an appreciation or really understand what it’s going for. So, I think grounded theory is something that the field hasn’t quite accepted yet in terms of ‘yes, that’s a valid way to do things.’”

The majority of participants also noted a bias toward “rigorous” research in comparison to research conducted by practitioners in their own classrooms. Specifically, participants perceived that the EER community was more accepting of research systematically conducted by trained scholars aimed at describing, predicting, improving, or explaining a phenomenon than research conducted by practitioners in their own classrooms. For example, one manuscript author stated, “the place where I feel like in education there’s a big difference between sort of teacher research and then the stuff that gets published in the journals. And the stuff that gets published in the journals tends to be fairly large or else fairly lengthy in various ways, and so potentially more rigorous.” One participant did note, however, that while there has traditionally been a bias against claims based on accounts of personal practices, that bias may be changing, “So, it’s changing…We’re starting to see more practice papers which I find really interesting. It is almost a bit confusing because I don’t think they go [in JEE].”

Publishing innovative research. Manuscript authors also perceived difficulty publishing theoretical frameworks, methodologies, and topics not traditionally prioritized by the field (e.g., “I think methodological innovation is also not accepted. So, methods that don't conform to our definition of what a method is or that are trying to push the boundaries of it are difficult to get in.”). Participants also noted that they felt is it difficult to publish papers that reconceptualize a popular theoretical frame or topic. For instance, one participant felt that they had difficulty publishing their manuscript because it discussed issues related to diversity and inclusion in a way that challenged mainstream views on underrepresentation in colleges of engineering.
Of those who discussed the difficulty of publishing innovative research, some participants indicated how this trend has impacted their professional development. For instance, one manuscript author noted that it was hard to recall traditional theoretical frameworks because he did not use them in his own work, "If you can cite what's considered the classics in your paper, then you'll have a good foundation of getting accepted. I can't even remember [them] because I found them really so useless for me." In contrast, another manuscript author felt that pushing boundaries may have negative professional consequences for her: "But maybe just to an earlier career person like me, it feels a little bit I have to be swallowing a certain carrot to be able to be successful here. And I guess seeing the same things being published and presented and stuff makes it seem like they're trends, and it makes it seem like I have to adhere to those."

Other emergent findings

**Need to define theoretical and conceptual frameworks.** When asked about which theoretical frameworks are welcome within the EER community and which are not, all but two of the manuscript authors conflated theory with methods or topics, or stated that they were not sure they understood the question. Frequently, participants’ responses to questions about theoretical frameworks involved statements about quantitative methods being preferred to qualitative methods. For example, when asked about which theoretical frameworks were welcome one participant said, "So I would say that there's definitely a focus on quantitative research methods, so any kind of statistical methods that you're going to be using, or a focus on large data sets, or large sample size. People love that and hope for that." It was also common for participants to reference popular or undervalued topics such as retention, diversity and inclusion, undergraduate students, or student performance. For instance, one participant expressed that one thing that is, “…lacking is conversations on cost and the economics of interventions, and what we do in the classroom.”

In addition to responding to questions about theoretical boundaries with perceptions regarding methodological and topical boundaries, several manuscript authors felt that they did not know how to answer the question or which theoretical frameworks were accepted or not accepted. Furthermore, one participant explicitly mentioned the need to define theoretical and conceptual frameworks as well as the purpose of each:

> I think we need to have a discussion of what is a conceptual framework, what is a theory, what is a theoretical framework. I think the advantage to what other fields, like education or behavior have, is that their journals have kind of defined that. Like, this is the theory journal. This is the systematic lit review journal. This is the quant journal. You sort of see that they've defined the boundaries of the things in their field based on the journal framings, and I think we're still deciding what that means.

**Discussion and implications**

The overarching goal of this project is to facilitate a discussion about the field’s theoretical, methodological, and topical boundaries which influence which questions are posed, how questions are addressed, and potentially, engineering education practices. As an emerging interdisciplinary field, EER aims to draw on a diverse set of research paradigms from multiple disciplines. However, the findings presented in this paper build on the findings of others (e.g., Beddoes, 2012; Douglas et al., 2010) who have suggested that EER is limited in both scope and methodological diversity. More specifically, the findings align with prior studies documenting limited understanding of grounded theory (Beddoes et al., 2014), an insufficient number of reviewers capable of adequately reviewing qualitative research (Beddoes, 2012), and a dominant emphasis on “rigorous” research (Beddoes, 2014).

By including the perspectives and experiences of scholars who are members of the EER community but never published in the premier engineering education journal, this project offers new material for the EER community to consider as the field develops and further advances its practices. Our sample contained primarily early career scholars (e.g., graduate
students, post-docs, and early-career faculty) who struggled to identify and successfully navigate the theoretical, methodological, and topical boundaries of the field. This may be due to the fact that such boundaries are not consistently applied, universally agreed upon, or well-understood within the field. Further critical reflection on these issues needed.

That said, the findings presented in this paper represent the perspectives of the manuscript authors we interviewed. All of these perspectives may not accurately represent the current goals or intentions of JEE or the boundaries of engineering education. Rather, they point to potential incongruences with respect to where the current boundaries of the field are across different members of the field. For example, the growing number of authors who have published qualitative research in the journal in recent years may not share the same perspective on the methodological boundaries of the field. These are types of issues we will explore as data analysis continues.

The findings point to a need for spaces aimed at facilitating emerging scholars’ understanding of engineering education research as a field and how to advance it. New professional development materials and workshops could further novices’ understandings of EER norms and expectations. Additionally, their perceptions and experiences highlight issues in need of reflection and discussion by the wider community.

JEE is currently undertaking its own efforts to improve peer review and to help potential authors. While our project is separate from their efforts, and our findings independent, we hope to identify and undertake synergistic initiatives with the journal in coming years. The journal’s editor serves on our advisory board and we will work with her to identify ways our findings can best contribute to JEE’s other efforts.

Acknowledgements

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References


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Exploration of the Ethics and Societal Impacts Teaching Practices of Anglo and Western European Educators

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Abstract: Ethical behaviour and awareness of societal context are important outcomes for engineering graduates, but cultural norms and practices likely vary globally. This study examined the ethics and societal impacts (ESI) instruction of engineering educators through a cultural framework. Survey responses from 1359 educators in the US, 125 in non-US Anglo, and 91 in Western European countries explored the course types, teaching methods, and assessment strategies associated with ESI education in the three cultural clusters. ESI is most commonly taught by US educators in engineering design and science courses whereas first-year introductory and professional issues courses are more prevalent for non-US Anglo educators and Western European educators more frequently indicated teaching ESI in post-graduate courses. Across all three clusters, educators reported using case studies, lectures, and professional scenarios for ESI instruction. This work aimed to improve our understanding of ESI education practices to better prepare engineers to work across cultural boundaries.

Context

Engineers are tasked with addressing a host of societal challenges that are becoming more complex and interconnected. The interplay between technology and its social and environmental implications necessitates the education of future engineers with an awareness of their ethical responsibility and the role they play in the broader context. With engineering companies drawing talent from around the world, it is also important to understand how engineers in different countries and cultures are educated about ethics and societal impacts (termed ESI). The engineering workforce is increasingly globalized with multinational firms preferring diversity and mobility in their employees (Lucena et al., 2008). This trend necessitates global competency in engineering (Downey et al., 2006), both in changing the way engineers are educated and understanding differences in how students are trained across cultural boundaries. The United States (US) and Europe are in the midst of redefining global competencies in engineering and are taking a similar trajectory but at different paces. In the US, the National Science Foundation (NSF), National Academy of Engineering (NAE), and American Society for Engineering Education (ASEE) have converged on engineering competencies and national identity in engineering education. In Europe, the movement is complicated by the formation of regional identities and differing definitions of what it means to be an engineer in terms of practical experience and formal training (Downey & Lucena, 2005). The international attention on ESI in engineering education warrants an examination of how this movement is being realized in the classroom. This research focuses on ESI education in the US, non-US Anglo (United Kingdom, Ireland, Australia, Canada, and New Zealand), and Western Europe, which includes the Germanic (Austria, Germany, the Netherlands, and Switzerland), Nordic (Denmark, Finland, Norway, and Sweden), and Latin (France, Israel, Italy, Portugal, and Spain) Europe sub-groups.

The literature describes differences in the development and practice of engineering ethics education in the US and Europe (Brumsen, 2005; Didier, 2015; Zandvoort, van de Poel, &
Brumsen, 2000). US and European approaches diverge in terms of the role of professional licensing, national and regional accreditation, historical practices, and cultural norms (Didier, 1999). The US has a longer history of engineering ethics education, which has enabled courses in the US to serve as reference points for European and Australian programmes (van de Poel, Zandvoort, & Brumsen, 2001; Zandvoort et al., 2000). However, other countries such as the Netherlands have developed their own practices that include influences from Science, Technology, and Society (STS) and an emphasis on the broader context. This differs from the "traditional American approach" that focuses on personal responsibilities as captured in codes of ethics (van de Poel et al., 2001, p. 269). Australia shares an emphasis on professional codes and certifications for professional licensing (Zandvoort et al., 2000) but has more of a macroethical emphasis on environmental protection and sustainability (Engineers Australia, 2010).

Differences between the clusters are also manifested in accreditation requirements. The Washington Accord established a common set of graduate attributes (IEA, 2017) but accrediting bodies in individual countries maintain significant influence over the programmes they accredit. ABET accredits programmes in the US and 30 other countries and mandates 'an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts' (Criterion 3, outcome 5; ABET, 2017). The European Network for Accreditation of Engineering Education (ENAEF) developed common attributes across Western Europe but it is not required and programmes can choose to be accredited only by agencies in their country (ENAEF, 2012). Accreditation requirements in the non-US Anglo cluster vary by country but share a commitment to macroethical issues such as sustainable development and environmental protection (Engineers Australia, 2008; Engineers Canada, 2018; Engineering Council, 2014).

Despite the reported differences in accreditation requirements, historical practices, and educational approaches, the course types, teaching methods, and assessment strategies associated with ESI education at institutions in the US, non-US Anglo, and Western Europe have not been well characterized and synthesized.

**Research Questions**

For each of the following research questions, survey responses from educators at institutions in the US, non-US Anglo, and Western Europe clusters were explored.

1. In which course types do educators teach ESI?
2. What methods do educators use to teach ESI?
3. What methods do educators use to assess ESI outcomes?

These questions are important to engineering education because there is international momentum to integrate ethical responsibility and societal context into engineering education (Byrne, 2012; Conlon & Zandvoort, 2010; Zandvoort et al., 2000). Despite work across continents to improve students' ESI outcomes, we posit that cultural differences influence educational practices. Since the engineering workforce is increasingly mobile and globalized, it is important to understand how students educated in different cultural settings learn about ESI. The research questions are structured around cultural clusters that serve as the theoretical foundation of this study.

**Theoretical Framework**

The theoretical framework underpinning this study is the GLOBE cultural clusters (Gupta, Hanges, & Dorfman, 2002; House et al., 2004). Cultural clusters provide an effective way to understand similarities and differences between societies, and are growing in importance in
parallel with the globalization of business. The GLOBE work builds off Hofstede’s (1980) influential study of culture, which used survey data from IBM employees in more than 70 countries to group countries using cultural dimensions. The GLOBE project includes more recent data and additional cultural practices and values to provide a more comprehensive cultural clustering (Alas, Gao, & Carneiro, 2010). Unlike the Hofstede clusters, the GLOBE clusters include the humane orientation as a dimension (“being fair, altruistic, generous, caring and kind to others”; House et al., 2004), which aligns closely with ethics (Alas et al., 2010). Alas (2006) used the GLOBE cultural clusters to study ethics because the perception of right and wrong “depends on culture and environmental circumstances and is different across the cultures” (p. 237). The study concluded, “dimensions of national culture could serve as predictors of how people desire high ethical standards in a particular society” (p. 243). Using this framework, we posit that cultural environment exerts an influence on ethics education, which is manifested in differences in where and how ESI is taught and assessed.

**Methodology**

This study employed a survey research design to explore the ESI instructional practices of educators at institutions in the three clusters.

**Data collection**

All research methods were approved by the Institutional Review Board for Human Subjects Research. The data presented in this paper were collected from surveys distributed electronically to educators to understand if and how they teach ESI in curricular and co-curricular settings. The first survey campaign from February to May 2016 was US-centric in both the survey language and distribution. Educators were invited to take the survey based on their publication of engineering ethics research, participation in ASEE divisions, award of NSF grants related to engineering ethics, and involvement in a range of engineering co-curricular activities such as service organizations, research programmes, and professional societies. Although the survey campaign focused on US educators, it also reached non-US Anglo and Western European educators through the dissemination strategy. The survey invitation was sent to ~5000 educators. Detailed information on the survey development and distribution has been published (Bielefeldt et al., 2016a, 2018a). The second survey campaign targeted non-US Anglo and Western European educators and included more internationally inclusive language (e.g., “graduate-level course” in the US survey reworded to “post-graduate course” in the international survey). For 41 non-US Anglo and 75 Western European institutions, the authors compiled contacts for one to three educators in each engineering and computing disciplinary unit. More information on the dissemination process has been published (Polmear et al., 2019). Survey invitations were sent to ~1300 educators at institutions in non-US Anglo and Western European countries, with invitations and reminders in July and August 2018 and responses collected from July to November 2018. Surveys were written in English, which may have limited the ability of some educators to participate or fully understand the questions.

The surveys from the two campaigns contained the same questions regarding how educators teach ESI in their courses. Respondents were first asked if they teach any topics related to ethics and the broader impacts of technology. The 18 listed options covered both microethics, the decisions and responsibilities of individual engineers, and macroethics, the responsibilities to society at large (Herkert, 2001), and were developed based on a literature review. If the respondents indicated at least one ESI topic, they were directed to questions on the courses in which they integrate these topics and the instruction and assessment methods associated with the course that they believe is most effective. The present study focuses on the respondents’ instruction as opposed to students’ overall exposure to ESI in the curriculum. The survey questions of interest, as motivated by the research questions, are shown in Table 1.
Table 1: Survey questions explored in this study

<table>
<thead>
<tr>
<th>Research Question</th>
<th>Survey Question</th>
<th>Response Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>RQ1: Course types</td>
<td>In what type of courses do you teach students about the societal impacts of engineering and/or ethics? (check all that apply)</td>
<td>9 options listed and other</td>
</tr>
<tr>
<td>RQ2: Teaching methods</td>
<td>In the ONE course where you believe you most effectively teach engineering and/or computing students about the societal impacts of technology and/or ethics: What methods do you use in this course to teach students about societal issues and/or ethics? (check all that apply)</td>
<td>15 options listed and other</td>
</tr>
<tr>
<td>RQ3: Assessment methods</td>
<td>In the ONE course where you believe you most effectively teach engineering and/or computing students about the societal impacts of technology and/or ethics: How do you assess students’ knowledge of the societal impacts of technology and/or ethics in this course? (check all that apply)</td>
<td>8 options listed, other, and do not assess</td>
</tr>
</tbody>
</table>

Participants

Across the two survey campaigns, 1359 US, 125 non-US-Anglo, and 91 Western European responses were collected. The response rate for the first campaign was 8-28% (Bielefeldt et al., 2018a). The number of respondents from each country in the non-US Anglo and Western Europe clusters and the response rates from the second campaign are shown in Table 2.

Table 2: Number of respondents from countries in the non-US Anglo and Western European clusters

<table>
<thead>
<tr>
<th>Non-US Anglo</th>
<th>n</th>
<th>Response rate, %</th>
<th>Western Europe</th>
<th>n</th>
<th>Response rate, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Australia</td>
<td>50</td>
<td>19</td>
<td>Spain</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>Canada</td>
<td>41</td>
<td>13</td>
<td>Portugal</td>
<td>14</td>
<td>16</td>
</tr>
<tr>
<td>UK</td>
<td>17</td>
<td>10</td>
<td>the Netherlands</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>New Zealand</td>
<td>12</td>
<td>17</td>
<td>Sweden</td>
<td>11</td>
<td>15</td>
</tr>
<tr>
<td>Ireland</td>
<td>5</td>
<td>6</td>
<td>Italy</td>
<td>10</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Germany</td>
<td>6</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>France</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Norway</td>
<td>5</td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Denmark</td>
<td>4</td>
<td>18</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Finland</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Switzerland</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Israel</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Austria</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>

Data Analysis

Descriptive statistics were calculated for respondents in each of the three clusters. To discern patterns across the three clusters, frequencies and medians are reported for the course types, teaching methods, and assessment methods. Fisher’s exact tests were conducted in SPSS 24 to compare variables between the independent groups; this test is more accurate for small samples than Chi-square (McDonald, 2014). Statistically significant differences were inferred when the 2-sided exact significance was less than 0.05. This analysis was conducted to explore potential variability in the ESI education practices between the US, non-US Anglo, Western European educators. The analysis was guided by
the theoretical framework to use cultural clusters to group and compare respondents. However, statistically significant differences cannot be attributed entirely to culture. Factors such as discipline, gender, and professional licensure can affect ESI teaching practices (Bielefeldt et al., 2016b, 2018a, 2018b). Other limitations are that the data are self-reported and the number of responses, especially for the non-US Anglo and Western Europe, cannot guarantee generalizability across the cultural clusters. As such, this analysis is intended to be exploratory using a cultural lens to discern patterns in ESI education.

**Findings and Conclusions**

Data and discussion are presented by research question in the following section.

**RQ1: Course Types**

The percentage of respondents in each cluster who reported teaching ESI in the listed course types is shown in Table 3. It should be noted that the number of respondents shown in Table 3 for each cluster is lower than the total number of respondents since only those who teach at least one ESI-related topic were asked to indicate the course types in which they teach ESI. Respondents could also skip any question on the survey. In addition, the language describing the course types is US-centric using terminology from ABET. Table 3 shows the language used in the non-US Anglo and Western European survey with differences in the US survey shown below in italics.

<table>
<thead>
<tr>
<th>Course Type</th>
<th>US, % (n=1153)</th>
<th>Non-US Anglo, % (n=108)</th>
<th>Western European, % (n=68)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capstone design (final year undergraduates)</td>
<td>40</td>
<td>33</td>
<td>15*</td>
</tr>
<tr>
<td>Senior capstone design</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Engineering science or engineering courses for undergraduates</td>
<td>40</td>
<td>28</td>
<td>43</td>
</tr>
<tr>
<td>Sophomore/junior core eng science or eng</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design-focused course for undergraduates (not including first-year or capstone)</td>
<td>32</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>in sophomore, junior, or senior</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First-year (FY) introductory</td>
<td>30</td>
<td>39</td>
<td>18*</td>
</tr>
<tr>
<td>Post-graduate level (any type)</td>
<td>30</td>
<td>29</td>
<td>44</td>
</tr>
<tr>
<td>Graduate-level</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Professional issues (at any level; e.g. project management, communications)</td>
<td>17</td>
<td>35*</td>
<td>28</td>
</tr>
<tr>
<td>FY design-focused</td>
<td>12</td>
<td>28*</td>
<td>6</td>
</tr>
<tr>
<td>Other (identify)</td>
<td>12</td>
<td>16</td>
<td>13</td>
</tr>
<tr>
<td>Humanities and/or social science</td>
<td>9</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td>Full course on engineering ethics</td>
<td>6</td>
<td>12*</td>
<td>18*</td>
</tr>
<tr>
<td>Median number of course types</td>
<td>2</td>
<td>2.5</td>
<td>2</td>
</tr>
</tbody>
</table>

*p<0.05 compared to US

The most common course types (in order of decreasing preferences) for educators at US institutions were senior capstone design, sophomore/junior core engineering science or engineering, and design-focused in sophomore, junior, or senior year. Although these settings were the most prevalent, only 40% or less of the respondents selected these courses, which raises questions about students’ exposure to ESI in the technical core of the curriculum. The most common course types (in order of decreasing preferences) for educators at non-US Anglo institutions were FY introductory, professional issues, and
capstone design. The most common course types (in order of decreasing preferences) for educators at Western European institutions were post-graduate level, engineering science or engineering courses for undergraduates, and professional issues.

Non-US Anglo educators indicated teaching ESI in professional issues, FY design (courses focused on design and project-based learning for FY engineering students), and full courses on engineering ethics more frequently than US educators. Courses focused on ethics and professional issues are important given that they provide greater depth and breadth than afforded in engineering courses that are crowded with technical content (Zandvoort et al., 2000), suggesting that students in the non-US Anglo may benefit from this exposure. Western European educators also integrated ESI in engineering ethics courses more frequently than US educators but less frequently in capstone design and FY introductory. Write-in responses for “other” included ESI across the entire curriculum (Australia, the Netherlands), research modules and courses (Australia), and sustainable development courses (Sweden).

Some of the variation between the clusters could be attributed to the types of courses that are offered or required at institutions in different cultural groups. For example, most US programmes do not have compulsory full courses on engineering ethics (Herkert, 2000) but “a culminating major engineering design experience” is required for accreditation (Criterion 5d; ABET, 2017). In addition, due to the survey distribution methods, which targeted engineering and computing educators, it is likely that the majority of these professors do not teach humanities and/or social science courses. This could explain the lower prevalence of this course type. However, general education and liberal arts courses are a more common requirement in US programmes than in Europe so there may be a greater integration of ESI in these non-engineering courses (Ross, 2017).

RQ2: Instructional Methods

The percentage of respondents in the three clusters who indicated using each method to teach ESI is displayed in Table 4 with the number of respondents who answered this question.

Table 4: Frequency of respondents in each cluster who reported using various methods to teach ESI

<table>
<thead>
<tr>
<th>ESI Teaching Method</th>
<th>US, % (n=1081)</th>
<th>Non-US Anglo, % (n=94)</th>
<th>Western European, % (n=62)</th>
</tr>
</thead>
<tbody>
<tr>
<td>In-class discussion</td>
<td>68</td>
<td>60</td>
<td>39*</td>
</tr>
<tr>
<td>Case studies</td>
<td>67</td>
<td>73</td>
<td>73</td>
</tr>
<tr>
<td>Lecture</td>
<td>65</td>
<td>64</td>
<td>60</td>
</tr>
<tr>
<td>Examples of professional scenarios</td>
<td>61</td>
<td>65</td>
<td>55</td>
</tr>
<tr>
<td>Engineering design</td>
<td>41</td>
<td>36</td>
<td>44</td>
</tr>
<tr>
<td>Project based learning</td>
<td>37</td>
<td>46</td>
<td>45</td>
</tr>
<tr>
<td>Guest lecture</td>
<td>31</td>
<td>36</td>
<td>19*</td>
</tr>
<tr>
<td>Videos</td>
<td>28</td>
<td>29</td>
<td>21</td>
</tr>
<tr>
<td>Reflection</td>
<td>25</td>
<td>47*</td>
<td>37</td>
</tr>
<tr>
<td>In-class debate and/or role-play</td>
<td>22</td>
<td>28</td>
<td>19</td>
</tr>
<tr>
<td>Think-pair-share</td>
<td>14</td>
<td>20</td>
<td>6*</td>
</tr>
<tr>
<td>Problem solving heuristic</td>
<td>14</td>
<td>13</td>
<td>15</td>
</tr>
<tr>
<td>Service-Learning/community engagement</td>
<td>13</td>
<td>12</td>
<td>3*</td>
</tr>
<tr>
<td>Humanist reading</td>
<td>9</td>
<td>12</td>
<td>5</td>
</tr>
<tr>
<td>Moral exemplars</td>
<td>8</td>
<td>16*</td>
<td>11</td>
</tr>
<tr>
<td>Other</td>
<td>6</td>
<td>12</td>
<td>13</td>
</tr>
<tr>
<td>Median number of methods</td>
<td>5</td>
<td>6</td>
<td>4</td>
</tr>
</tbody>
</table>
The most common teaching methods for the US cluster (in order of decreasing preference) were in-class discussion, case studies, and lectures. Case study was the most common for non-US Anglo educators followed by examples of professional scenarios and lecture. Case study, lecture, and examples of professional scenarios were the highest reported methods for the Western European cluster. The prevalence of case studies across the clusters aligns with the pedagogical approach most commonly cited in the literature for engineering ethics education (Colby & Sullivan, 2008; Hess & Fore, 2017). The results suggest that educators across the clusters rely on the same instructional foundation, which could be in part attributed to the longer history of ethics education in the US and European and Australian programmes borrowing from those approaches (van de Poel et al., 2001; Zandvoort et al., 2000).

There are statistically significant differences for moral exemplars (positive cases or narratives of engineers acting ethically in practice) and reflection for the non-US Anglo cluster compared to the US. Results also indicated that Western European educators less frequently use in-class discussion, guest lecture, think-pair-share, and service-learning/community engagement. The prevalence of “other” for non-US and Western European educators suggests that the US-centric development of the survey may have neglected teaching approaches that are more common outside of the US. Examples of write-in responses included paper writing (Sweden, the Netherlands), cultural immersion (Australia), workshops (Canada), and research (Australia, Canada).

**RQ3: Assessment Methods**

Survey participants were asked to indicate the methods they use in their most effective course to assess students’ knowledge of ESI. The results are shown in Table 5 with the number of respondents in each cluster who answered this question on the survey.

**Table 5: Frequency of respondents in each cluster who reported using various methods to assess students’ knowledge of ESI**

<table>
<thead>
<tr>
<th>ESI Assessment Method</th>
<th>US, % (n=1077)</th>
<th>Non-US Anglo, % (n=94)</th>
<th>Western European, % (n=62)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Individual reflective essays</td>
<td>40</td>
<td>53</td>
<td>22*</td>
</tr>
<tr>
<td>Individual homework assignment, essay, and/or papers that are graded with a rubric</td>
<td>40</td>
<td>30*</td>
<td>19*</td>
</tr>
<tr>
<td>Test and/or quiz questions</td>
<td>37</td>
<td>33</td>
<td>24*</td>
</tr>
<tr>
<td>Group-based written assignment</td>
<td>33</td>
<td>42</td>
<td>23</td>
</tr>
<tr>
<td>Individual homework assignments where questions have fairly straight forward right and wrong answers</td>
<td>16</td>
<td>1*</td>
<td>5*</td>
</tr>
<tr>
<td>Team ratings</td>
<td>15</td>
<td>13</td>
<td>13</td>
</tr>
<tr>
<td>Do not assess these learning outcomes</td>
<td>14</td>
<td>7</td>
<td>16</td>
</tr>
<tr>
<td>Others</td>
<td>13</td>
<td>25*</td>
<td>10</td>
</tr>
<tr>
<td>Surveys</td>
<td>10</td>
<td>6</td>
<td>6</td>
</tr>
<tr>
<td>Individual standardized assessment method (DIT, EERI, ESIT, or similar)</td>
<td>1</td>
<td>0</td>
<td>3</td>
</tr>
<tr>
<td>Median number of methods</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
</tbody>
</table>

*p<0.05 compared to US

Individual reflective essays, individual assignment graded with a rubric, test/quiz questions, and group-based written assignment were most commonly selected across the three
clusters. Individual homework assignments with straightforward right and wrong answers were more commonly used by US educators. In the US-centric version of the survey, the Fundamentals of Engineering (FE) exam was used as an example of this assessment method and this language was removed from the non-US Anglo/Western European survey since the FE is part of the professional licensing process in the US (NCEES, 2019). The results reflect the greater emphasis on professional licensing in the US than non-US Anglo and Western European questions since more educators may use FE-style questions for their course assessment to prepare students for the exam. The higher occurrence of “other” for the non-US Anglo could be in part attributed to the US-centric survey design, which may not have included more internationally prevalent methods.

The results indicate that standardized methods such as the DIT (Defining Issues Test; Schlaefli, Rest, & Thoma, 1958), ESIT (Engineering and Science Issues Test; Kerr, Brummel, & Daily, 2016), and EERI (Engineering Ethical Reasoning Instrument; Zoltowski, Buzzanell, & Oakes, 2013) were very rarely used by educators in the three clusters. Although significant resources and effort have been devoted to developing, testing, and refining these assessment methods, they do not appear widespread in application. This could reflect a lack of knowledge of available tools or an interest in using methods that are customized to the course or learning outcome. Although ethical knowledge can be evaluated with exam questions, such as the NCEES FE, and ethical reasoning can be assessed to varying degrees with standardized instruments, such as the DIT, the aspirational outcome of ethical behaviour is challenging to assess in the classroom. Furthermore, without formal training and knowledge of ESI, engineering educators may struggle to develop rubrics or find resources. Assessment is an important part of national accreditation in all of the clusters so future work could explore challenges and opportunities for improvement.

Recommendations and Implications

This paper aimed to explore the course types, teaching methods, and assessment strategies associated with ESI education at institutions in the US, non-US Anglo, and Western European countries. This research looked through the lens of cultural clusters, but there are a number of factors beyond culture that can influence how and where ESI is taught in engineering. Previous work has examined differences in topic selection and perceptions of ESI education sufficiency based on cultural clusters while controlling for gender, discipline, survey solicitation, and whether or not the respondent taught ESI (Polmear et al., 2019). Future work could examine course types, teaching methods, and assessment strategies while controlling for these covariates.

This work is intended to be exploratory and to shed light on how students across these clusters are being educated about ESI, which can improve our understanding of transcultural ESI education. The results indicate similarities and differences across the three clusters for each of the research questions. Respondents in the three clusters indicated varying settings in which they integrate ESI. Course types have different advantages and limitations for ESI, which can impact student learning. The integration of ESI in engineering design and science courses affords the opportunity to contextualize the technical content and convey the relevance of ESI to engineering practice (Zandvoort et al., 2000). The prevalence of ESI in FY introductory courses taught by non-US Anglo educators suggests that students receive exposure to these topics early in the curriculum and that foundation is built upon in dedicated engineering ethics and professional issues courses. Overall, the data indicate opportunities to improve ESI across the curriculum.

The results suggest the value of learning from educators in the other clusters about how to effectively teach ESI in different course types. The similarities in teaching methods indicate an opportunity to share best practices across international contexts since US, non-US Anglo, and Western European educators all rely on case studies, lectures, discussions, and
examples of professional scenarios. Differences between the clusters suggest ways that ESI can be expanded, such as US educators drawing on work in non-US Anglo countries related to reflection and moral exemplars and Western European educators working with peers in the US to integrate ESI via guest lectures and service learning.

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Moving from crime and punishment to success and reward: transitioning from technical to educational research

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Abstract: Many engineering academics interested in quality teaching and learning dabble with educational research. Some go further leaving their technical research field behind to embark head-long into what for many is an initially bewildering and conceptually challenging domain. Often peers perceive this transition as a crime (giving up on real engineering) liable to be punished with reduced access to funding and institutional recognition for one’s research. The Australasian Association for Engineering Education (AAEE) has been sponsoring a Winter School in Engineering Education Research Methods since 2011, to help engineering academics change their transition story from one of crime and punishment to success and reward. While helpful, this transition is not a simple matter of learning new techniques but of altering one’s perspective and habits of thinking and behaviour. Many participants find this both challenging and at least initially, a lonely pursuit. In this paper, participants in the 2018 school ask the question “what enables and hinders the transition to educational research”.

Introduction

Engineering education remains an emerging field of research within the Australian context (Gardner & Willey, 2018) as well as in other parts of the world (Alias & Williams, 2011; van
Hattum-Janssen, Williams, & De Oliverira, 2015). Few formal programs exist for training engineering education researchers, especially outside of the United States, which results in academics often completing their tertiary studies in technical engineering disciplines before later transitioning into engineering education research (Borrego & Bernhard, 2011). Many papers have been written about this transition, however these have tended to focus on the associated challenges in order to identify the knowledge and practices that need to be acquired (Borrego, 2007; Streveler, Borrego, & Smith, 2007). Of particular interest has been understanding the paradigm shift required to engage in quality engineering education research which is transferable across contexts and answers the deeper “why” questions for learning in engineering (Douglas, Koro-Ljungberg, & Borrego, 2010; Streveler et al., 2007).

The Australasian Association for Engineering Education (AAEE) has been sponsoring an annual five-day Winter School in Engineering Education Research Methods since 2011 in response to an identified need to both assist the transition of current and new researchers into engineering education research and to improve the quality of this research. The objectives of the program which is facilitated by experienced researchers include to:

- improve research practice through workshops with experts,
- explore research methodologies and data analysis techniques,
- provide an opportunity for peer review of work, and the development of academic writing skills,
- build community and a reference group for students and academics whose interests are often unique in their home departments, and
- develop career paths for participants.

The topic most requested by participants has been to learn more about research. In 2018, the school spent the first two days on epistemology and methodology of qualitative research allowing participants to gain a better understanding of why certain data-gathering methods might be used, as well as how best to use them, the third day focused on methods per se, the fourth day on data analysis and the fifth day on writing. As well as the standard qualitative methods such as interviews, the methods part of the School introduces some less familiar approaches such as transect walks, sentence frames and systematic observation. As research methods are developed through experience involving collaboration, application, feedback and reflection, it is hard to achieve more than introducing participants to the skills in the short timeframe available. To address this, participants are offered the opportunity to take part in subsequent online discussion of topics of their choice. In 2017, the post-Winter School discussions focussed on observational methods and resulted in a journal paper being published (Matemba, Parker, & Jolly, 2018) in the AAEE journal. In 2018 these discussions have focused on applying participant’s learning from Winter School to a collaborative research project exploring their transition to becoming engineering education researchers.

In this paper the transition experience of five participants of the 2018 AAEE Winter School is examined through the lens of Bourdieu’s Theory of Practice (Bourdieu & Nice, 1977). This theory incorporates three concepts – field, habitus and capital – offering insights into how individuals interact and behave (habitus) within their environment and social structures (field), based on the recognised currency (capital). Here the field is considered to be departments/faculties of engineering in Australian universities, which engineering education represents a part thereof. The aim of this paper is to explore the habitus and capital factors that enable or inhibit the success of engineering education researchers within the field to improve participant’s outcomes and assist those transitioning to engineering education research.

**Background**

Bourdieu’s Theory of Practice provides a useful perspective to investigate the transition of technical researchers into educational research as this theory allows insights and understanding of educational questions that are not readily visible with other approaches.
In the transition from technical to educational research, we seek to explore why transitioning researchers behave in particular ways within a given cultural context and how that can be understood using Bourdieu’s Theory of Practice. This theory has three elements: field, capital, and habitus through which to view and investigate this transition.

The field can be best understood as a “configuration of relations between positions objectively defined, in their existence and in the determinations they impose upon the occupants, agents or institutions” (Bourdieu & Wacquant, 1992, pp. 72-73). A field is interpreted by Webb, Schirato, and Danaher (2002, pp. 21-22) as:

A series of institutions, rules, conventions, categories, designations, appointments and titles which constitute an objective hierarchy, and which produce and authorise certain discourses and activities. (Webb et al., 2002, pp. 21-22)

There are different kinds of capital present in any field, and participants compete for and with the capital to improve their position in the field. In engineering education research, the capital available is similar to the wider engineering research field and to the broader field of higher education. Hence, to understand their transition it is important to understand the different forms of capital available and the sources of that capital (Jolly, 2016). It is in the competition for and distribution of the various forms of capital that the “configuration of relations” that make up a field becomes observable.

The medium of...relations [in a field] ...is capital, which is hence both product and process within a field. All capital – economic, social and cultural – is symbolic, and the prevailing configurations of it shape social practice (Grenfell & James, 2004, p. 510).

Bourdieu refers to the habitus as the subjectively generated rules, values and dispositions commonly held by members of a field. Mutch (2006) refers to habitus as “knowing what, knowing who and knowing how” (Mutch, 2006, p. 167). Hence habitus can be understood as the attitudes, beliefs and practices gained from our history that:

... generally stay with us across contexts (they are durable and transposable). These values and dispositions allow us to respond to cultural rules and contexts in a variety of ways (because they allow for improvisations), but the responses are always largely determined - regulated – by where (and who) we have been in a culture. (Webb et al., 2002, p. 44).

There have been several previous instances of using Bourdieu’s theory in engineering education research. In particular, Jolly (2016) applied Bourdieu’s theory to pedagogical content knowledge in engineering education, while Kloot (2011) applied it to understanding engineering education foundation programs in South Africa.

**Methodology**

Academics who are not only interested but have already initiated their move towards engineering education research are arguably in the best position to tell the story of transition. The AAEE Winter School participants were earnestly trying to step into the field of engineering education research, so willingly participated in the five-day program. All participants in the Winter School were invited to join a collaborative research project at the conclusion of the program.

Five participants from the 2018 cohort took part in this research. All five participants were from different institutions, academic rankings (ranging from PhD candidate, associate lecturer, lecturer, senior lecturer and reader (associate professor)) and geographic locations within Australia. After the Winter School, the participants and two Winter School facilitators collaborated on the project through regular meetings using the online video conferencing tool Zoom.
The five participants interviewed each other about their experience of moving into engineering education research and the associated challenges. While we acknowledge the potential for participants to unintentionally, frame their responses using the chosen Bourdieuvian categories, we did not regard this as a shortcoming of our methodology, as the intention of the research was to have participants reflect on their own experiences. In addition, the interviewer/interviewee roles provided the transitioning researchers with a valuable development opportunity.

The interviews were semi-structured and were guided by the interview protocol that was developed collaboratively by the participants. Consent was obtained from all participants in accordance with the ethical clearance. The interview questions were designed to solicit information on capital within the field of engineering faculties in Australian universities. We were particularly interested in identifying the range of capital and the relative importance of each in enabling or inhibiting participation in engineering education research. We also investigated the habitus of the participants, and how this impacted the acquisition of capital as well as participation in the sub-field of engineering education research. The semi-structured interview protocol was divided into two parts. The first part focused on exploring the individual’s understanding of engineering education research, whereas the second part focused on their transition experiences so far and their future aspirations.

A Bourdieuvian analysis was applied to the data to uncover how these transitioning academics experienced the rules of the field and the pursuit of advantageous capital. We also analysed the impact of the habitus (or patterns of behaviour) they brought with them, and how this may be influenced to ease the transition to educational research and maximise effectiveness once there.

**Results & Discussion**

The participants in this study were prepared for professional engineering practice through their undergraduate degree in the science, technology, engineering and mathematics (STEM) disciplines. Some had pursued work as practising engineers before returning to a university position, others had moved directly into work in the university sector. For our participants, personal interest in teaching was a primary motivator for participating in the higher education field in engineering:

> My intention when I came to Australia to do the PhD was to go back to India and do teaching …I got this teaching intensive position, and I was really happy because that was what I wanted to do.

In contrast to other members of the field, our participants did not regard teaching as an interruption to a research career, but as the primary and intrinsically motivating core of their work. They had been actively engaged in the scholarship of teaching and learning before becoming aware of, and deciding to pursue, rigorous engineering education research. Participants expressed dissatisfaction with pursuing research in technical engineering research, being motivated to join the subfield of engineering education research by an appetite to experience the impact of their research and scholarship directly through their teaching:

> I enjoyed the teaching and educational side of things much more than the PhD I was doing. I had a very fun time there so. I also thought I was much better at teaching and educational side of stuff and the impact I think I can have in education is lot bigger than anything I could have got out of … continuing research into the traditional mechanical engineering. So I think that is the main reasons that made me kind of jump.

> I really don’t want to go back to technical research because I was enjoying the teaching, and if I was doing technical research, that time I could devote to doing education research, because that can help my teaching.
They felt that the legitimacy of the engineering education research subfield is not widely acknowledged by other engineering field participants. They expressed a view that many in the field see education research as a pursuit belonging to education faculties (hence not engineering research) or as being undertaken by discrete pockets throughout the engineering academy (hence, being niche, having less impact and importance). It was also expressed that the legitimacy of the education research endeavour has been undermined as academic roles in Learning and Teaching units are being replaced by professional staff, such as learning designers or teaching fellows. Given these roles are often associated with reduced or no mandate to pursue research, it signals that the university and subsequently many in the field, do not consider teaching and learning a research pursuit.

Capital

As subfields of higher education, the capital associated with engineering education research is similar to the capital of typical technical engineering research. This includes publications in journals with a high impact factor, high citation counts, and increasingly grant income. Members of the field who accumulate this capital have a dominant position in the field of higher education, and conversely those without such capital do not. Journal impact factors vary across disciplines. For example, the impact factor for a selection of IEEE journals is listed in Table 1. The journals specific to a technical area have impact factors much higher than the IEEE Transactions on Education which has an impact factor of 1.6. Indeed, the highest ranked journal in engineering education research, the Journal of Engineering Education, has an impact factor of 1.976. However, education researchers in engineering departments are likely to be judged against their technical researcher peers. This practice contributes to the perceived lower status of engineering education research:

[The] faculty includes a lot of academics and most of them are involved in technical research so [engineering education research is] not really viewed highly by academics and also researchers that I speak to on a day to day basis …[and] other PhD students.

This explains why another participant talked of the pressure to “pump out” technical research, taking time away from their educational research. As journal impact factors are linked to the potential readership of journal papers, the lower impact factors in part, reflect a smaller research community. Engineering education is also a different research area in that often the research is focused on improving developmental and educational outcomes as opposed to stimulating other research. Hence, journal readers are not necessarily researchers but, for example, educationalists, practitioners and academic developers focused on improving educational outcomes. This is different to most technical engineering research areas where the end-users are typically other researchers who build on research and subsequently cite each other’s papers.

Table 1: Selection of IEEE journal impact factors

<table>
<thead>
<tr>
<th>Journal name</th>
<th>Journal Impact Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>IEEE Industrial Electronics Magazine</td>
<td>10.429</td>
</tr>
<tr>
<td>IEEE Transactions on Pattern Analysis and Machine Intelligence</td>
<td>9.455</td>
</tr>
<tr>
<td>IEEE Communications Magazine</td>
<td>9.270</td>
</tr>
<tr>
<td>IEEE Wireless Communications</td>
<td>9.202</td>
</tr>
<tr>
<td>IEEE Transactions on Cybernetics</td>
<td>8.803</td>
</tr>
<tr>
<td>IEEE Signal Processing Magazine</td>
<td>7.451</td>
</tr>
<tr>
<td>IEEE Transactions on Education</td>
<td>1.600</td>
</tr>
</tbody>
</table>
In addition, locally within Australia and New Zealand, the absence of a specific engineering education Field of Research (FOR) code contributes to reduced capital in the subfield of engineering education research. The Australian and New Zealand Standard Research Classification (ANZSRC) have FOR classifications that allows research and development (R&D) activity to be categorised according to the field of research. The categories in the classification include major fields and related sub-fields of research and emerging areas of study investigated by businesses, universities, tertiary institutions, national research institutions and other organisations. The FOR codes are a hierarchical classification with three levels, specifically, Divisions (2 digits, for example engineering is 09), Groups (4 digits, for example civil engineering is 0905) and Fields (6 digits, for example construction engineering is 090502).

Each Division is based on a broad discipline. Groups within each Division are those that share the same broad methodology, techniques and/or perspective as others in the Division. The ANZSRC states that the FOR codes consider the methodology used in the research area. Hence Groups and Fields of research are categorised to the Divisions sharing the same methodology rather than the Division they support. Currently there is no 09 engineering code for engineering education. This means many researchers in Australia and New Zealand have to categorise their research under a 13 Education code or 099999 Engineering not elsewhere classified reducing its visibility and value while also contributing to a perception that engineering education research is peripheral to the discipline.

For many researchers across the whole higher education sector the viability of their project depends on whether it has attracted funding. Similarly, for our participants this means that when the money runs out the project often stops:

[The] money ran out and the college didn't want to keep supporting the … education space.... So after a few months of that I decided to leave.

However, participants felt that technical engineering researchers have access to more sources of funds than researchers in engineering education:

Even tapping into the university funding I have found … quite hard to argue for funding… I'm sure there would be some kind of pockets that could be tapped into but I'm unaware of these.

One participant knew of funding available through their Deputy Dean to support teaching and learning projects but in specific topic areas such as student success and retention. These funds available through internal faculty sources are typically small amounts focussed on evaluating teaching and learning practices or creating new teaching and learning resources rather than supporting educational research. This contributes to the perspective that education is something we are all involved in and fails to recognise the need to include the evidence informed approaches of engineering education research in these activities.

While many of our American colleagues have successively accessed National Science Foundation (NSF) funding for engineering education research, in Australia successful access to the Australian Research Council (ARC) grants for engineering education research is generally viewed as being problematic and/or extremely difficult. There is a perception that without an engineering FOR code, an engineering education grant will find it hard to compete against broader educational research grants. Firstly, educational grants are often assessed by members of education faculties (who have their own habitus, expectations and perceptions of what they value as capital) not engineering education researchers. Secondly because project quality and innovation, assessed using the following criteria, represents 40% of the overall discovery grant selection criteria there is perception that applications focusing on engineering education will find it hard to compete with education applications with broader outcomes:

1. the extent to which the research addresses a significant problem;
2. evidence that the conceptual/theoretical framework is innovative and original;
3. potential for the research to contribute to the Australian Government’s Science and Research Priorities;
4. the extent to which the research project includes aims, concepts, methods and results which will advance knowledge; and
5. the extent to which the research has the potential to enhance international collaboration.

We suspect it is probably a combination of the current habitus of engineering education researchers (being influenced by both how the field and we view our research) combined with the often unacknowledged need to improve the quality and impact of our research that contributes to this perception. In any case, the perception feeds the belief of there being reduced access to the existing capital for engineering education researchers.

With little access to the forms of capital mentioned above, intrinsic motivation was found to be the primary driver for pursuing engineering education research for the participants in our study – as mentioned earlier. They pursue this research as it aligns with their personal interests and values:

*First of all it helps with my teaching, gives me a lot of data about my teaching.*

*Anything that involves working with humans and trying to develop a better experience for humans is what I perceive engineering as and engineering education. That is what I am really interested in and that won't change for me.*

*I always have found that sort of thinking about … learning processes and how people learn really interesting and stimulating, what it means to learn, what knowledge means.*

Personal motivations and values played a significant role in participants’ decisions to persist with engineering education research. These included an interest in understanding how people learn and how this could be improved, feeling a sense of wanting to help people, wanting to improve classroom teaching and learning experiences, and a desire to enhance how engineers operate in industry with respect to social and environmental considerations. These motivations align with those identified by Alias and Williams (2011) and Borrego and Bernhard (2011).

*It's [education research] been always the interesting part of my job - reading the literature and then the question for me is whether doing the research is part of what I want to do or just to have time to engage in reading in what other people write in the literature and putting it into practice.*

*I really enjoy being in this space, I think that I can do a lot of things to help people again in this area more so than in their technical research that I was doing.*

However, one participant believes that undertaking educational research will improve his teaching which will be rewarded at his institution:

*I'll be doing more informed activities and so be doing the right things… and that will improve my teaching which will help me with my career as well as helping students.*

**Habitus**

Like most academics in engineering education research, the participants in our study completed technical undergraduate engineering degrees. With the exception of one participant, each had also completed their doctoral studies in a technical engineering topic and then took up engineering education research at a later stage of their career. Completing undergraduate and postgraduate studies in technical engineering disciplines usually presents a hurdle to be overcome for conducting engineering education research, as this experience typically prepares participants for a technical academic career. Most technical research does not provide an introduction to the qualitative methods, theories and approaches used in engineering education research. Hence this required participants to develop new habitus appropriate to the engineering education research sub-field as part of their transition. This was
emphasised by participants when discussing their gaps in understanding engineering education research with statements such as:

*I think I had a fairly clear view [of what engineering education research was] fairly early on in the process and it was just trying to develop the skills myself is something that I have not devoted much time to until now.*

*I have only a little information about [education theory]. I did not use anything so far. The project I’m involved in is not at a stage to use any theory.*

*I kind of stumbled across engineering education by mistake but … incorporated those different perceptions of reality and took them into consideration.*

In line with the findings of Borrejgo (2007), participants described their technical research in terms of well-accepted theories and methods for collecting evidence. In contrast, participants described engineering education research as requiring measurement of things much harder to quantify. This distinction is an example of technical engineering studies not preparing academics for tackling educational problems where different methods need to be employed. Consequently, participants expressed that transferring from an established habitus to a different sub-field posed challenges:

*My technical research was very much mathematical analysis, very much things that you could prove to make the world simpler or the problem simple enough - assume enough things so that you can then mathematically analyse everything and prove something and come up with a theorem.*

*[In my technical research] we could quantify the errors in it and say this assumption was made so obviously it would have impacts on the results. I feel like [engineering education research] is more difficult to quantify that kind of error.*

*The evidence was really looking at … an experiment that was already done physically in practice, and then comparing that to the model [I was developing]. And then obviously if it was similar then the model was validated.*

In order to address the gaps, participants recognised the importance of socialising with peers to develop their expertise in engineering education research, and to increase their sense of belonging in the sub-field. Participants have shown to be proactive in seeking out developmental opportunities, both formal and informal, as well as generating their own opportunities such as forming a community of practice and identifying mentors that enable this sharing. Quotes from participants which support this include:

*I would say that our winter school group is [one of] the most sustained groups I’ve communicated with beyond my school*  
*[I’ve got] a main person that I go to for anything specific about engineering education research.*

*So, because I don’t have any research allocation in my role, I started doing a little bit of research in my own time last year. I started a small group with the physics people, like a physics education research group.*

However, a lack of collaborators and community participating in the engineering education research sub-field, particularly at the local level, was identified as an inhibiting factor. Participants frequently discussed the lack of academics interested in engineering education research within their home institutions. For example:

*Sometimes I just go and knock on my supervisor’s door just to have a different type of talk and let out some of my frustration and to speak to someone that is interested in engineering education.*

*[There is] no one that I can talk with [about engineering education research]…not sure I can continue – like I said there is no team.*
Given the difficulties previously discussed in transitioning to engineering education research, we ask what we should do as a subfield to strengthen our identity and assist those who wish to make the transition. The winter school experience has demonstrated the need to provide a sense of community and identity for these transitioning researchers. The fact that the participants have maintained weekly Zoom meetings for the last seven months demonstrates how much they value these discussions and the research practice involved in producing this paper. For most participants, if not for these meetings they would be the sole member or at best a part of a very small group of engineering education researchers within their home institutions. This suggests that as engineering education researchers we need to form cross-institution research groups and collaborations. For example, the two winter school facilitators contributing to this paper are currently endeavouring to develop a collaborative engineering education research group between their two universities. This will increase the profile of engineering education research as the capital of research students, research supervision opportunities, publications, impact and grants will be contributed to by academics at both institutions. Hence, the volume and impact of these measurable forms of capital will be larger than either institution could achieve on their own. It also provides prospective and transitioning engineering education researchers access to a wider pool of expertise and experience to collaborate with, be socialised into the subfield of engineering education research (change their habitus) and more opportunity to access the available capital.

Beyond this, like any emerging research domain, it is up to the established researchers to change the narrative around, and current perceptions of, engineering education research through improving the quality and impact of their research and increasing their access to the available capital. This would have a positive impact on engineering education research’s recognition in the field (engineering) and the habitus and belief to access the field’s capital for those transitioning to and participating in engineering education research.

Conclusions

In this paper, we explored the experience of five participants of the 2018 AAEE Winter School transitioning into engineering education research using Bourdieu’s Theory of Practice. Each of our participants entered the field of higher education through an undergraduate degree in a technical STEM discipline, before being drawn to engineering education research later in their career. Each participant identified perceived constraints in accessing capital within the field caused by the transition. This included a lack of access to grant funding, a reduction in the perceived significance of research due to structural influences like impact factors and field of research codes, and more limited career progression opportunities. Strong intrinsic motivation to pursue educational research, which formed part of participants’ habitus, was found to contribute significantly to their decision to pursue engineering education research in spite of the reduced access to capital. Here participants expressed motivations around understanding how people learn, wanting to help others, improving educational experiences, and enhancing how engineers operate in society. The formation of the cross-institutional community of practice which emerged out of the 2018 AAEE Winter School was identified as a key strategy in overcoming the small number of engineering education researchers within individual institutions, which enabled socialisation of engineering education research concepts and experiences in the field. Improving the transition experience of engineering education researchers in developing new habitus and effectively leveraging capital will enhance the uptake and reputation of engineering education research. However, this needs to be accompanied by current researchers recognising and responding to the need to improve the quality and impact of engineering education research and advocating for changes to structural factors such as in the Australian New Zealand context the allocation of an engineering
education FOR code. These changes will have a positive influence on the habitus and enable greater access to capital for current and future participants in the sub-field.

References


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Development of Socio-Technical and Co-Design Expertise in Engineering Students

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Abstract: Universities are challenged to educate engineers with a broad set of attributes, including socio-technical and co-design expertise, which will enable them to tackle wicked problems. In this study, we ask: To what extent do courses on human-centred design and systems engineering analysis impact students’ development of socio-technical and co-design expertise? We used scenario-based assessment in a pre-/post-design to evaluate the development of these two attributes in two separate units at two Australian universities. The results show some small changes in the responses students gave to the scenario-based tool, at the end of each course. However, the analysis showed that students were still distant from the optimal levels of socio-technical and co-design expertise required of graduates. Therefore, we suggest that such one-off courses are insufficient to develop socio-technical and design expertise. Instead, we argue that engineering programs need to integrate opportunities to develop such expertise throughout all year levels.

Introduction

Globalization, emerging digital technologies, and the need to address global change are increasingly pushing engineers to face wicked problems, for which conventional approaches and solutions are not enough. As a consequence, Seager, Selinger, and Wiek (2012) proposed that universities need to cultivate education programs that foster ethical awareness, participatory approaches, and cross-disciplinary exchanges. Similarly, Bordogna (2004) suggested that industry demands “a holistic breed of engineers – graduates with the skill to work across intellectual, social, and cultural boundaries” (para. 17). In engineering design, this is especially important because projects often fail when engineers do not have the competencies needed to consider the integration of both the technical and social domains of their work, including engaging stakeholders (Mattson & Wood, 2014).

In this study, we investigated how socio-technical and co-design expertise are developed in a first-year course on human-centred design and a second-year course on system engineering analysis at two Australian universities. We define socio-technical expertise as the ability to integrate both technical and social dimensions in engineering projects, and co-design expertise as the ability to involve stakeholders at each stage of the design process (Daniel & Mazzurco, under review; Mazzurco & Daniel, under review).

Specifically, using a pre-/post-design, we tested the following hypotheses:

- H1: socio-technical expertise level of students in both courses will increase at the end of the course.
H2: co-design expertise level of students in both courses will increase at the end of the course.

Additionally, given that we collected data at the very beginning of the first-year students’ degree (that is, the week before they started their very first course) and at the end of the second year of the second-year students (which marks the halfway point of their degree), we conducted a cross-sectional study by testing the following hypothesis:

- H3: the socio-technical expertise level of second-year students at the end of their course will be higher than that of the first-year students at the beginning of their degree.
- H4: the co-design expertise level of second-year students at the end of their course will be higher than that of the first-year students at the beginning of their degree.

This way, we were able to compare a group of typical novices (that is, first-year students prior to any of their engineering studies) and students at the mid-point of their education. However, we did not investigate or make any claims about any differences between the two courses.

Literature review

In the following sections, we provide a brief overview of the literature and frameworks on which we based our study and discuss findings from previous studies on this topic.

Socio-technical expertise

The notion that engineering is a purely technical discipline is fading away as research on engineering practice consistently shows that engineering requires the integration of both technical and social dimensions. As a result of an extensive ethnographic study of building-design engineers, Faulkner (2007) concluded that “all engineering, is, of necessity, both technical and social” (p. 351) and therefore “good engineering (as in engineering which is effective) demands the thorough integration of these elements” (p. 351). This is especially important in engineering design, which has the goal to “achieve clients’ objectives or users’ needs” (Dym, Agogino, Eris, Frey, & Leifer, 2005, p. 104). In fact, non-technical factors, such as empathy towards users and stakeholders, and contextual listening, are often cited as key dimensions of engineering work (Fila, Hess, Purzer, & Dringenberg, 2016; Hess & Fila, 2016; Leydens & Lucena, 2009; Wood & Mattson, 2016; Zoltowski, Oakes, & Cardella, 2012).

In our previous work comparing novices and experts’ socio-technical expertise, we found that a socio-technical expert is someone that can integrate considerations focused on three domains: technology, people, and broader context (Mazzurco & Daniel, under review). The technology domain comprises all those considerations that focus exclusively on technical aspects, including required inputs, constraints to the technology, and long-term technical issues. The people domain includes considerations that focus on direct or indirect stakeholders’ needs, desires, and other characteristics, and how to involve these stakeholders in the project. The broader context domain comprises considerations that focus on the cultural and social norms of the community, the legal frameworks, ethical considerations, economic system, impact on the environment, and other socio-material contexts. We used this framework for analysis of the data in this study.

Co-design expertise

The issue of stakeholders’ participation in projects is not only an engineering topic, but has been long investigated in the social sciences and creative disciplines. For instance, one of the first efforts to characterize different levels of participation was by Arnstein (1969), who proposed a “citizen participation ladder” comprised of 8 hierarchical forms of participation. The lower levels of the ladder are more top-down, where citizens do not have much control over the decision-making process. Conversely, at the higher levels of the ladder there are more bottom-up forms of participation where citizens are empowered to make decisions. Building on Arnstein’s ladder, Hart (1992) proposed a similar ladder to characterize children’s
participation in UNICEF projects. Hart (1992) places tokenistic projects at the bottom of the ladder, where children are only given a voice on paper, but not in practice. Conversely, at the top of Hart’s (1992) ladder, there are projects in which children are empowered to initiate projects and decision-making is shared with adults.

Similar efforts to characterize stakeholders’ participation have been developed for technology and engineering design. For instance, Druin (2002) identified four roles that a child can play in the design of a technology: user, tester, informant, and design partner. In her framework, as users, children are involved only once the technology has been developed, while as design partners, they are involved in every step of the design process. Similarly, Mazzurco, Leydens, and Jesiek (2018) identified three forms of stakeholders’ participation in design for development: passive, consultative, and co-constructive. At the passive level, stakeholders are not involved in any aspect of the design process, whereas at the co-constructive level, stakeholders and engineers collaborate throughout the design process.

In our previous research on co-design expertise, we used the above frameworks to compare novices and experts. We found that experienced practitioners (i.e. experts) tended to consider stakeholders as “design partners” (Druin, 2002) and to engage in “co-construction” (Mazzurco et al., 2018) throughout the design process. On the contrary, the novices typically did not describe stakeholder involvement at all (Daniel & Mazzurco, under review).

**Methodology**

This paper is part of a larger ongoing research project focused on investigating the development of socio-technical and co-design expertise, including novice-experts, pre-post, comparative, and longitudinal studies. Specifically, in this study, to test our hypotheses, we used a pre-/post-design in which a scenario-based tool, the Energy Conversion Playground (ECP) design task (Daniel & Mazzurco, under review; Mazzurco & Daniel, under review; Mazzurco, Huff, & Jesiek, 2013; Mazzurco, Huff, & Jesiek, 2014), was distributed to two groups of students at the beginning and end of their courses. Their responses were then analysed with a rubric we developed in previous studies and compared using non-parametric statistical tests. This paper reports the first study using ECP to evaluate pre-post changes. Details of this methodological approach are provided in the following sections.

In developing countries, energy production is one of the most critical problems. Resources or technologies to produce energy are often not available. Thus, human power conversion systems might be used to power small appliances. Imagine that you and your team are assigned to a design project in partnership with a Non-Governmental Organization (NGO) of a developing country. The NGO needs a low-cost power system that can generate enough energy for the lights of a primary school. One of the members of your team suggests using merry-go-round, seesaw, and swing to produce energy that can be converted to electricity for the lights.

**Questions 1:** What considerations do you need to take into account to solve the problem described in the scenario? List and describe all constraints and justify their inclusion.

**Question 2:** How would you proceed to solve the problem described in the scenario? List and describe concisely all the steps you would take to solve the problem described in the scenario.

![Figure 1: The ECP design task (adapted from Daniel and Mazzurco (under review) and Mazzurco and Daniel (under review)).](image)

**Data collection**

Our main instrument of data collection was the ECP design task. As illustrated in Figure 1, this instrument presents a scenario in an international development context and asks participants to respond to two questions. The first question was developed to elicit socio-technical considerations from participants, whereas the second is meant to capture the respondents’ design approaches. For both groups, the ECP was distributed in paper-based
form at the beginning and end of the two courses, together with a brief demographic survey. The ECP was previously validated with novices and experts and showed it was able to identify differences in expertise (Daniel & Mazzurco, under review; Mazzurco & Daniel, under review).

Data analysis

The responses of each participant to the two questions were scored using the rubrics in Tables 1 and 2. The rubrics were developed by comparing the responses of experienced practitioners and novices (Daniel & Mazzurco, under review; Mazzurco & Daniel, under review). The first two authors scored all the responses of the students and met periodically to come to consensus. The agreement between the two authors’ scoring ranged between 60% and 85%. Once all the responses were scored, non-parametric statistical tests were used to test our hypotheses.

The first rubric assesses the socio-technical expertise of respondents by scoring the responses to the first question on the three domains discussed earlier in the literature review: technology, people, and broader context. While the scoring logic for each domain is slightly different (as reported in Table 1), respondents that provided a sophisticated response in one domain received a score of 3 for that domain, and if they did not include a consideration related to a domain they received a score of 0 for that domain. Therefore, respondents who scored 3 in all domains are considered socio-technical experts within our framework.

### Table 1. Rubric to score responses to question 1 of the ECP design task (adapted from Mazzurco and Daniel (under review)).

<table>
<thead>
<tr>
<th>Technology</th>
<th>People</th>
<th>Broader context</th>
</tr>
</thead>
</table>
| Considerations focus on three technical categories:  
1) Inputs or constrains to the technology  
2) functionality  
3) long-term technological considerations | Considerations focus on involvement of direct users and broader stakeholders | Considerations focus on three contextual categories:  
1) Local norms  
2) Ethics and Law  
3) Other socio-material contexts |
| Does not mention any inputs/constraints, functional factors, or long-term technical considerations. | Does not mention people in any way. If they mention people as either source of energy (e.g., number of kids needed to generate power), or in relation to safety (e.g., “it can’t be dangerous to the people using it”), does not count as people (but as input in technology). | Does not mention contextual consideration |
| Mentions one or more considerations belonging to one of the three technical categories | Mentions people / community / children’s needs, skills and expertise, desires. AND/OR Presenting / talking at them, educating / training | Mentions one or multiple considerations within a single consideration, without articulation. |
| Mentions one or more considerations belonging to two of the three technical categories | Mentions listening to, communicating with, or involving people (direct users and other stakeholders) | Mentions considerations belonging to 2 or 3 categories OR writes a well-articulated |
The second rubric assesses the co-design expertise of respondents by scoring the responses to the second question on three design phases: scope, develop, and deliver. As reported in Table 2, activities that focused on defining the problem and understanding the stakeholders and the design context, were coded in the scope design phase, those focused on conceptual and detailed design as develop, and those focused on implementing, maintaining, and evaluating the design in the long-term were coded as deliver. For each design phase, the score is based on the extent to which stakeholder participation is described. That is, the higher the score, the more the responses reflected an intention to involve stakeholders. This scoring logic is further illustrated in Table 2.

**Table 2. Rubric to score responses to question 2 of the ECP design task (adapted from Daniel & Mazzurco (under review))**

<table>
<thead>
<tr>
<th>Scope</th>
<th>Develop</th>
<th>Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Stakeholder research</td>
<td>- Brainstorm / ideate</td>
<td>- Produce, manufacture, build, installation</td>
</tr>
<tr>
<td>- Context research</td>
<td>- Selection</td>
<td>- Implementation</td>
</tr>
<tr>
<td>- Identifying design requirements</td>
<td>- Prototype</td>
<td>- Education</td>
</tr>
<tr>
<td>- Test</td>
<td>- Iterate</td>
<td>- Monitoring, Evaluation, and maintenance</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not mentioned</td>
<td>Not mentioned</td>
<td>Did not include any reference to the activities typically belonging to the design phase.</td>
<td>Mentioned</td>
<td>Mentions at least one activity belonging to the design phases, but does not mention any form of engagement with stakeholders.</td>
</tr>
<tr>
<td>Mentioned</td>
<td>Information transfer</td>
<td>Mentions at least one activity belonging to the design phases and includes reference to some form of transfer of information between engineers and stakeholders.</td>
<td>Co-constructive</td>
<td>Mentions at least one activity belonging to the design phases and includes reference to a collaborative approach of doing so.</td>
</tr>
</tbody>
</table>

**Context and participants**

The data was collected from two group of students. The first was from a first-year course on human-centred design (ENG1 from hereafter) and the second from a second-year course on system engineering analysis (ENG2 from hereafter).

ENG1 is a term long (six weeks), intensive engineering course focused on human-centered design in the context of humanitarian engineering. This is the very first course students undergo, in a new practice-based engineering degree. During the course, the students go through the entire design cycle to develop conceptual designs for projects developed as part of the Engineers Without Borders (EWB) Challenge (Jolly, Crosthwaite, & Kavanagh, 2010). Therefore, students are exposed to multiple topics related to the focus of this study, including stakeholder and context research, developing design requirements, brainstorming design ideas, selecting design ideas, detailed design, implementation, maintenance, and stakeholder engagement. However, the students did not have the opportunity to directly contact their primary users.
Twenty-eight students were enrolled in ENG1 when the pre-data was collected and 26 students completed the ECP design task (92.8%). At the end of the course, 21 students completed the post-course task (77.8%). However, we were able to match only 16 responses (59.3%), which is still more than half of the students enrolled. Of the 16 matched respondents, 4 were women. One respondent did not provide demographics information.

ENG2 is a one-semester (twelve-week) course focused on tools and approaches to undertake systems analysis during up-stream engineering design activities such as problem-scoping, system-level design, and requirements analysis. It runs in semester 2 and is a compulsory course for all students. Most students in ENG2 have completed a first semester course on engineering systems design, although for some students in articulation programs, it is their first semester of studies at the institution, having already completed two-years of study at their home institution overseas. ENG2 is a project-based course, with students learning a range of analysis methods, including research ethics, quantitative and qualitative data collection, and social, cultural, safety and risk perspectives, and how these should factor into engineering design and analysis. Teams of five apply these methods to an open-ended project with a mix of individual and group assessment.

There were 190 students enrolled in ENG2 when data was collected. Eighteen students (9.5%) provided complete responses to the ECP design task and the demographics survey at the beginning of the course and 21 (11.1%) responses were collected at the end of the course (one of these respondents provided responses only to question 1). Of the 18 students who provided demographics information at the beginning, 8 were females. While the response rate is too low to make any strong claims about the overall trends in this course, it is still enough to provide some insights for future research.

**Limitations**

The main limitation of this study was the low response rate across the two courses, especially ENG2. In addition, for ENG2, we were unable to match the pre- and post-responses. This impacted our ability to make generalizable claims and as such we were conservative in our claims in the discussion and conclusion sections. Other limitations include the extent to which scenario-based assessment predicts behavior, and un-investigated differences between the student populations enrolled at the two universities. Nonetheless, the data still provide some interesting insights, which can be used to inspire further research in this important topic and to further validate the ECP design task.

**Findings**

In the sections below, we report results of testing the hypothesis using Wilcoxon tests (Agresti, 2010). Because we conducted multiple tests with the same sample, we applied a Bonferroni correction to evaluate the significance of each test (Larpkiatworn, Muogboh, Besterfield-Sacre, Shuman, & Wolfe, 2003). Specifically, because for each sample we ran 6 tests (three for socio-technical expertise and three for co-design expertise), we used a corrected alpha of 0.0083 (that is, 0.05 divided by 6) in alignment with the Bonferroni correction.

**Hypothesis 1**

We hypothesized the students in both courses would increase their socio-technical skills, which we evaluated using the rubric reported in Table 1. Specifically, each respondent was given a score for the technical, people, and broader context domains and we tested whether their score in each domain changed. Table 3 reports the results of these tests for both ENG1 and ENG2. The results show that the median scores for technology remained the same for students in both courses. Some changes in median scores can be seen in the people and broader context domains. Both student groups increased their broader context median scores. ENG1 students also increased their median people score, while ENG2 decreased it. However, none of these results are significant with the Bonferroni correction.
Table 3. Test results for socio-technical domains of expertise

<table>
<thead>
<tr>
<th>Groups</th>
<th>n</th>
<th>Technology</th>
<th></th>
<th>People</th>
<th></th>
<th>Broader context</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Median</td>
<td>p-value</td>
<td>Median</td>
<td>p-value</td>
<td>Median</td>
<td>p-value</td>
</tr>
<tr>
<td>ENG1</td>
<td>Pre</td>
<td>16</td>
<td>2.5</td>
<td>1</td>
<td>0.5</td>
<td>0</td>
<td>0.041</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>16</td>
<td>2.5</td>
<td>1</td>
<td>0.627</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td>ENG2</td>
<td>Pre</td>
<td>18</td>
<td>2</td>
<td>0.29</td>
<td>1</td>
<td>0.5</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>21</td>
<td>2</td>
<td>0</td>
<td>0.047</td>
<td>0</td>
<td>0.801</td>
</tr>
</tbody>
</table>

Hypothesis 2

Similarly to hypothesis 1, we hypothesized that students in both courses would increase their co-design skills, which we evaluated using the rubric described in Table 2. Specifically, each respondent was given a score on three phases: scope, develop, and deliver, and we then tested whether each cohort’s distribution of scores changed after instruction. Table 4 reports the results of these tests. The results follow the same trends as those reported in Table 3. Even if some changes in medians are reported, none of the changes are statistically significant with the Bonferroni correction.

Table 4. Tests results for co-design phases

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Scope</th>
<th></th>
<th>Develop</th>
<th></th>
<th>Deliver</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Median</td>
<td>p-value</td>
<td>Median</td>
<td>p-value</td>
<td>Median</td>
<td>p-value</td>
</tr>
<tr>
<td>ENG1</td>
<td>Pre</td>
<td>16</td>
<td>1</td>
<td>0.041</td>
<td>1</td>
<td>0.095</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>16</td>
<td>2</td>
<td>0.592</td>
<td>2</td>
<td>1</td>
<td>0.524</td>
</tr>
<tr>
<td>ENG2</td>
<td>Pre</td>
<td>18</td>
<td>1</td>
<td>0.592</td>
<td>1</td>
<td>0.029</td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Post</td>
<td>21</td>
<td>1</td>
<td></td>
<td>1</td>
<td>0</td>
<td>0.104</td>
</tr>
</tbody>
</table>

Hypothesis 3

For our third hypothesis, we wanted to compare the socio-technical skills of students who had not received any engineering training (i.e. all the 26 ENG1 students who completed the ECP prior to the start of the course) and those at the end of their second year of their studies (ENG2 post). Table 5 reports the results of these tests. The only difference in median was for the broader context, but also in this case the difference in the distributions of scores was not significant.

Table 5. Tests results for socio-technical domains of expertise

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Technology</th>
<th></th>
<th>People</th>
<th></th>
<th>Broader context</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Median</td>
<td>p-value</td>
<td>Median</td>
<td>p-value</td>
<td>Median</td>
<td>p-value</td>
</tr>
<tr>
<td>ENG1</td>
<td>26</td>
<td>2</td>
<td>0.640</td>
<td>0</td>
<td>0.156</td>
<td>0</td>
<td>0.093</td>
</tr>
<tr>
<td>ENG2 Post</td>
<td>21</td>
<td>2</td>
<td></td>
<td>0</td>
<td>0.156</td>
<td>2</td>
<td>0.093</td>
</tr>
</tbody>
</table>

As shown in Table 1, scores in the technology and broader context domains depend on respondents mentioning considerations belonging to three sub-categories. Therefore, even if two respondents received the same score for a domain, they could have mentioned different aspects of that domain. As a consequence, we further looked at how the responses were distributed within the two domains and compared the two student groups. The distribution of the responses is reported in Table 6. For the technology domain, we observe similar trends in their responses. Both groups of students focused highly on inputs or constraints to the technology, whereas long-term considerations were not as commonly mentioned. There are, however, more evident differences between the two groups’ patterns of response in the broader context domain. While the two student groups had a similar focus on local norms, the ENG2 students mentioned ethical considerations more frequently than the ENG1 students.
Table 6. Response distribution within the technology and broader context domains

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Technology</th>
<th></th>
<th>Broader context</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inputs / constraints</td>
<td>Functionality</td>
<td>Long term</td>
<td>Local norms</td>
</tr>
<tr>
<td>ENG1</td>
<td>26</td>
<td>100%</td>
<td>77%</td>
<td>54%</td>
<td>19%</td>
</tr>
<tr>
<td>ENG2 Post</td>
<td>21</td>
<td>95%</td>
<td>95%</td>
<td>43%</td>
<td>14%</td>
</tr>
</tbody>
</table>

Hypothesis 4

As with our evaluation of socio-technical skills, we compared ENG1-pre and ENG2-post co-design responses. Table 7 reports the results of these tests. For both scope and develop, the median scores of 1 suggest that both groups mentioned activities within these design phases, but tended not to mention any form of involvement of the stakeholders in these design phases. Differences in scores for deliver were the only significant result, showing that ENG1-pre students described the deliver phase in their responses more than the ENG2-post students. The effect size of this difference was calculated with Cliff’s Delta (Torchiano, 2018), which gave a delta estimate of -0.56. This suggests a moderate difference between the two distributions given that the values +1 and -1 indicate complete absence of overlap.

Table 7. Tests results for socio-technical domains of expertise

<table>
<thead>
<tr>
<th>Groups</th>
<th>N</th>
<th>Scope</th>
<th>Median</th>
<th>p-value</th>
<th>Develop</th>
<th>Median</th>
<th>p-value</th>
<th>Deliver</th>
<th>Median</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENG1</td>
<td>26</td>
<td>1</td>
<td>0.652</td>
<td></td>
<td>1</td>
<td>0.014</td>
<td></td>
<td>1</td>
<td>&lt;0.001</td>
<td></td>
</tr>
<tr>
<td>ENG2 Post</td>
<td>21</td>
<td>1</td>
<td></td>
<td></td>
<td>1</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Conclusions and discussion

The most striking outcome of our pre-/post- analysis was the lack of a result. That is, neither ENG1 nor ENG2 led to any statistically significant changes in student scores on any of the dimensions of socio-technical or co-design expertise. One interpretation of these results is that even if there was significant learning in these areas, the combination of the small sample sizes and the coarseness of our instrument (measuring only on a 3-point scale) meant these changes went undetected. Our interpretation, however, is that these results indicate that it takes time to develop such expertise. Apart from in the technology domain, student scores were far below what would suggest expertise. Even in technology, where we might expect engineering students to score the highest, only about half of students identified any long-term technical design considerations.

We argue that these results suggest that to develop such expertise in students, educators must invest more time throughout undergraduate degree programs for students to learn about, apply, and reflect on these skills, through opportunities for deliberate practice. It is also worth to note that while both courses used a project-based approach, in none of them students had external engagement with clients, decreasing the authenticity of the experience and therefore perhaps impacting the results. Furthermore, features of these results (e.g. the comparative under-weighting of long-term technical considerations, the general lack of broader contextual considerations (especially apart from local norms or ethics), etc.) can be used in learning design to ensure students focus on aspects they otherwise may overlook or undervalue.

Although there were no significant differences in the pre-/post- analysis within the two student groups, there were nevertheless two interesting differences between the results from the two student groups. First, the ENG2 students, at the halfway point in their degree, scored lower on the delivery design phase than the ENG1 students at the start of their degree. University training often under-emphasizes such long-term considerations of maintenance and evaluation (Russell & Vinsel, 2019), and this finding corroborates that, with such considerations not figuring highly in the second-year students’ responses. Second, there were differences in the types of broader context issues identified. Overall, ENG2 students
scored higher in the broader context domain, with considerations mainly identified in the Ethics dimension. Conversely, almost all ENG1 considerations categorised as broader contexts were under local norms. Perhaps this is a reflection of different emphases given to such considerations in the different units, or of differences between the student cohorts. For example, ENG2 students have not undertaken the EWB Challenge, and instead in their course focus on more high-level ‘Science, Technology, and Society’ type issues.

In any case, these comparisons have been a fruitful reflective prompt for discussion between ourselves as educators, to consider what differences in our teaching could have led to these variations, and what learning strategies and resources we could employ to ensure our students develop an awareness of a variety of broader contextual considerations.

In conclusion, we see the key takeaways from this study being, first, that single units may not be enough to induce large changes in students’ socio-technical and co-design expertise, and therefore engineering programs need to offer opportunities for their students to develop such skills throughout their degree programs, and support for students to make links across these different experiences. Second, it appears that the ECP is better suited to detect differences in expertise across a longer timespan (e.g., novices vs experts, first years vs second years), rather than the effect of a single unit, that may result only in very small changes. Further research needs to be conducted to confirm this observation and thus determine the best application of the ECP. Nevertheless, results from using the ECP are a fruitful prompt for educators to reflect on their related teaching and learning practice.

References


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Do Teaching and Learning Environments Influence Students’ Conative Domain Development?

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Abstract: This study investigates the level of conative domain of three different groups of first year engineering students taking introductory engineering courses in their respective programs. A multiple case study research design was conducted with 18 respondents who went through different teaching and learning environment in the introductory engineering courses. Data were collected through document review, interview sessions and in-class observations. In-class observations were based on the four lenses of the How People Learn framework. Thematic analysis was carried out to analyse the interview data. The results showed that different teaching and learning environment has varying impact on students’ level of conative domain. Students who had undergone an introductory engineering course that fulfilled the four criteria of the HPL framework achieved the highest level of conative domain. This study confirmed that selecting an effective teaching and learning environment had a positive influence on students’ level of conative domain.

Introduction

Engineering graduates are expected to develop their knowledge, professional skills and attitude associated with the 21st century attributes as they prepare for novel challenges in Industry 4.0 (World Economic Forum, 2016). To help the students become successful engineers, they must possess a high level of conation which imbue them with striving behavior to enhance their potential to learn as well as to gain a successful transition during learning in an engineering program. Conation is the act of striving to perform at the highest levels (McDougall, 1932). Levels of conation consists of five stages: perception, focus, engagement, involvement and transcendence (Atman, 1987). Students with higher levels of conation will improve their professional skills and persist better in an engineering program (Hochanadel and Finamore, 2015).

To improve students’ learning, Tinto (2012) stated that students will persist better in an environment which allow them to be socially and academically involved during the learning
process. The first year is the most crucial and exhausting part in university life where the amount of academic failure and unsuccessful transition always happened (Hillman, 2005). Educators are responsible to create good teaching and learning environments to ensure students are able to achieve the highest level of conative domain to sustain them in university life and beyond. Hence, many engineering programs put efforts to improve the teaching and learning environment in guiding the first-year engineering students, amongst them through an implementation of introductory engineering courses (Samsuri et al., 2017).

In the university studied, the introductory engineering courses was implemented in various programs. Each program implemented different teaching and learning environments that yielded different impact on student’s conation. The objective of this study is to investigate the impact of different teaching and learning environments in three different introductory engineering courses to seek how do the learning environments prepare first year students to develop the different levels of conation.

Theoretical Background
Conative Taxonomy

According to American Heritage Dictionary of English Language (1971), conation is defined as the aspect of mental processes or behavior directed toward action or change that includes impulse, desire, volition and striving. Conation have to do with striving, will, volition and is intertwined between cognition and affection (C.V. Good, Dictionary of Education, 1973). McDougall (1932) stated that conation is the way we try, strive, endeavor, pay attention, focus, working hard, exert ourselves or doing our utmost to complete an action. Assagioli (1973, 138) described that conation is the will to complete an action, or a purposive action with the clear vision of goals to be achieved. Students who have aims in goal setting are essential to become more productive (Locke and Latham, 1984) and students trained using goal-oriented activities leads to a better academic performance (DeCharms, 1976).

Atman (1987), as cited in Huitt and Cain (2005) introduced five stages of conative taxonomy associated with striving behavior. As shown in Table 1, the five stages are; (i) perception, (ii) focus, (iii) engagement, (iv) involvement and (v) transcendence. The conative stages enable the individual to assess and examine their pattern of motivational behavior and develop their skills towards becoming more active.

<table>
<thead>
<tr>
<th>Conative Stages</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage 1 Perceptron (PR)</td>
<td>The individual opens all form of sensory and intuitive stimuli. The energy rate in this stage is low</td>
</tr>
<tr>
<td>Stage 2 Focus (FC)</td>
<td>The individual bring item, information to a clear relief and distinguish it from the background. He/she set the goal</td>
</tr>
<tr>
<td>Stage 3 Engagement (EN)</td>
<td>The individual is now goal-focused. Begin to work with all information, raising questions</td>
</tr>
<tr>
<td>Stage 4 Involvement (IN)</td>
<td>The individual thoroughly engaged in considering information, energized and work vigorously for project completion</td>
</tr>
<tr>
<td>Stage 5 Transcendence (TR)</td>
<td>The individual immerses him/herself in the task in such a manner that the mind/body/task become one. Participating the task wholly, totally, without self-recrimination.</td>
</tr>
</tbody>
</table>

Teaching and learning environment to promote conation

Students at high level conative taxonomy pursue knowledge voluntarily with their intention to strive in improving their understanding, develop self-competencies and applying the knowledge for sustainability. This is associated with the aims of higher education learning to produce the engineering graduates who are knowledgeable as well as emotionally intelligent and a lifelong learner (Paimin et. al., 2017). The success of learners depends on two factors (i) conative domain in terms of striving skills and (ii) carefully constructed teaching and learning environment. A successful student must be active and possess the “staying power” on intrinsic motivational ability through systematic interaction learning environment. Not every student has
this capability to strive by their own. Therefore, it is important for educators to take action in developing students’ conation (Atman, 1987).

Teaching and learning environments are the most important factor that could affect student’s success in a classroom (Geisinger and Raman, 2013). Students were more likely to succeed if they perceived that there was support and encouragement in their learning environment. Instructors assist students to ‘learn how to learn’ in an active environment. Students should be guided to learn in a team to solve a problem-based situation. Learning in cooperative manner can improve peer interaction, become self-regulated learner and enhance their striving behaviour to learn (Baillie & Fitzgerald, 2000).

To define an effective learning environment, this study adopts the How People Learn (HPL) Framework (Bransford, Brown and Cocking, 2000) as a basis to determine its effectiveness in the observation of the selected introductory engineering courses. The HPL framework was derived from a meta-analysis of various strong researches and supported by various learning theories. It consists of four lenses or criteria, which are knowledge, learner-, assessment-, and community-centred that are overlapping to define an effective learning environment as shown in Table 2 below. According to Svinicki (2010), the four criteria in the HPL framework need to be aligned and mutually supported to enhance students’ motivation and maximize their will to learn (conation). Effective learning environments also to help students persist in learning engineering (Samsuri et al., 2017).

Table 2: HPL Framework Criteria

<table>
<thead>
<tr>
<th>HPL Criterion</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Knowledge-centered (KC)</td>
<td>The interconnection between knowledge learned in different courses to the fundamental discipline and helps students to make connections to real-world situations.</td>
</tr>
<tr>
<td>Learner-centered (LC)</td>
<td>Instructor consider students’ prior knowledge, skills and belief that they bring into the course so that the instructor is able to guide students during the learning process.</td>
</tr>
<tr>
<td>Assessment-centered (AC)</td>
<td>Refers to the implementation of formative assessment. Formative assessment describes the feedback by community (peer and instructor) to the individuals that are assessed regularly to improve students’ self-development.</td>
</tr>
<tr>
<td>Community-centered (CC)</td>
<td>Refers to the supportive learning community that undergoing an active learning environment. Learning in community can influence students’ skills as they receive support, assistance and guidance from their peers and instructor</td>
</tr>
</tbody>
</table>

Methodology

The first year is the biggest challenge to an institution because it involves students’ transition from school environment to the university that may affect their development to learn at the tertiary level and beyond (Hillman, 2005). Many universities put efforts in supporting the first-year students, among them through an implementation of introductory engineering (IE) course. IE course has been introduced since 2010 in the studied university and is compulsory for all first-year engineering students. The IE courses in different engineering programs implemented its own aims, objectives and different types of teaching and learning environment, leading to different outcomes, especially on students’ conation.

In this study, a multiple case study research design was used to gather data through document review, interview sessions and in-class observations at selected IE courses in a university in Malaysia. Before collecting the data, the researcher has gained permission to conduct the study from the faculty administrator, and permission to collect data in the courses from the lecturer, academic staff and students involved.

The document review was conducted through collecting the course information (CI) at three different programs: engineering program A, engineering program B and engineering program C. The CI was reviewed and investigated to understand the teaching and learning environment happened in each course. Table 3 shows the implementation of introductory engineering course at Course A, B and C, which includes different credit hours, assessment and teaching and learning (T&L) approaches.

In-class observations were conducted throughout the semester (September 2018-December 2018) to observe the learning environment in each course (referring to the HPL framework).
The researcher noted down every assessment and activity in the classes using an observation field notes, supported by videos and pictures to avoid misconception and for future references. Considering that all HPL criteria might exist in all courses at different levels of implementation, the researcher set out the categories to differentiate the levels of each criterion. The four criteria of HPL framework are evaluated based on definition of (i) low (the instructor considers the HPL criterion but do not practically implement in the classroom), (ii) medium (the instructor implements the HPL criterion but it is not systematically conducted throughout the semester) and (iii) high (the instructor implements the HPL criterion and is systematically conducted throughout the semester) (Samsuri et al., 2017).

Table 3: The implementation of introductory engineering courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Course B</th>
<th>Course C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Credit Hours</td>
<td>- 3 credit hours</td>
<td>- 2 credit hours</td>
</tr>
<tr>
<td>Details</td>
<td>- 4 students/group - 2 instructors (team teaching) -40 students</td>
<td>- 15-20 students/group - 1 instructor (lecturing) - 60 students</td>
</tr>
<tr>
<td>T&amp;L approach</td>
<td>- Cooperative Problem-Based Learning (Cooperative Learning+ Problem-Based Learning)</td>
<td>- Project-based Learning - Teaching research nexus (through peer reading assignment, field trip)</td>
</tr>
<tr>
<td>Assessment</td>
<td>Report on Engineering Overview, Ethnic case study, Quiz (1,2), CPBL Report (Stage 1,2,3), Presentation (Stage 1,2,3), Video, e-learning, PR, PI, PTN (Stage 1,2,3), Test</td>
<td>In-class participation, Assignment 1, Reflective report (1,2), Project Management, Presentation, Report</td>
</tr>
</tbody>
</table>

Table 4: Example of codes under themes “Meaningful Experiences”

<table>
<thead>
<tr>
<th>Theme</th>
<th>Codes</th>
<th>Respondent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Meaningful experiences</td>
<td>Great experiences</td>
<td>RA1, RA2, RA6</td>
</tr>
<tr>
<td></td>
<td>Values of task</td>
<td>RA4</td>
</tr>
<tr>
<td></td>
<td>Memorable</td>
<td>RA2, RA4</td>
</tr>
<tr>
<td></td>
<td>Keep the knowledge forever</td>
<td>RA3</td>
</tr>
<tr>
<td></td>
<td>Keep what I’ve learnt</td>
<td>RA5</td>
</tr>
<tr>
<td></td>
<td>feel sad when the course is finish</td>
<td>RA2, RA3</td>
</tr>
<tr>
<td></td>
<td>Will be missed</td>
<td>RA2</td>
</tr>
</tbody>
</table>
Findings and Discussions

Table 5 shows the element of How People Learn (HPL) criteria that influence students’ level of conation obtained from document review, in-class observations and interview sessions. Each course was implemented to give an overview of engineering fields. While course A explicitly states that the aim of the course was to support students during the transition to the university from school, this was not written in the course information of courses B and C. However, from the class observations there were some teaching and learning activities that had this intention which is in course B, and none in course C. From the results each introductory engineering course implement different teaching and learning approaches, where Course A implemented a highly students-centered environment using cooperative problem-based learning, Course B using project-based learning and Course C using seminar style learning. Each course has different credit hours, approaches, aims and assessment. The teaching and learning environment for each course was investigated based on the HPL criteria, as stated in Table 5 which describes the environment happens during the learning process.

Table 5: Element of HPL criterion in different introductory engineering courses

<table>
<thead>
<tr>
<th></th>
<th>Course A</th>
<th>Course B</th>
<th>Course C</th>
</tr>
</thead>
<tbody>
<tr>
<td>KC</td>
<td>High</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td>- Using Cooperative problem-based learning which interconnect the assessment with real world problem</td>
<td>- Project-based learning through project formulation and management</td>
<td>- Using seminar-type lecture where each topic was taught by different experts</td>
</tr>
<tr>
<td></td>
<td>- Instructor constructs 3 stages of sustainability problem, lead students to continually improves as the problem get tougher</td>
<td>- Instructor provide in-class activities, industrial talk, field trip and mini project</td>
<td>- Instructor brief on the overview of engineering discipline &amp; provide assignment</td>
</tr>
<tr>
<td></td>
<td>- Students understand the problem deeply through individual, peer teaching, and recommend engineering solution</td>
<td>- Mini project require students to collaborate in multidisciplinary group to produce innovative solution</td>
<td>- Students complete assignment related to engineering disciplines individually and in group</td>
</tr>
<tr>
<td>LC</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>Instructor provide scaffolding and guidance to students in every stage</td>
<td>- Students get general overview to complete the project through industrial talk &amp; field trip</td>
<td>- Lack of engagement between students-instructor due to change of instructor every week based on their topic expertise</td>
</tr>
<tr>
<td></td>
<td>- Peer teaching assessed students’ level of understanding and instructor guide students to avoid misconception</td>
<td>- No specific guidance by instructor to prepare students working in the multidisciplinary group</td>
<td></td>
</tr>
<tr>
<td>AC</td>
<td>High</td>
<td>Middle</td>
<td>None</td>
</tr>
<tr>
<td></td>
<td>- Students get regular feedback for every assessment they have completed obtained peer rating in every stage so students can improve from their mistake</td>
<td>- Feedback were given few times during project formulation (at the middle and end of project)</td>
<td>- Students never receive feedback during the learning process</td>
</tr>
<tr>
<td>CC</td>
<td>High</td>
<td>Middle</td>
<td>Low</td>
</tr>
<tr>
<td></td>
<td>- Learning in cooperative environment with 4 member/team (throughout overall semester)</td>
<td>- Students learn in a multidisciplinary group (15-20 students) and collaborate to complete a mini project</td>
<td>- Students only get to work in a group of 4/team (at the end of the semester) Collaborate to complete a project assignment</td>
</tr>
<tr>
<td></td>
<td>- Students participate actively in peer teaching and overall class peer teaching and became independent learner</td>
<td>- Lack of preparation to work in a big group and manage a project</td>
<td></td>
</tr>
</tbody>
</table>

Level of Conative Taxonomy

(TR) Life-long learning
- Willingness
- Expedite
- Enthusiasm
- Natural Tendency

(EN) Unpreparedness
- Procrastinate
- Lack of basic knowledge

(IN) Fun learning
- Interesting
- Impressed
- Excited

(FC) No satisfaction
- Low engagement
- No attention

(FC) Knowledge
- Separation of disciplines

FC- Focus, EN- Engagement, IN- Involvement, TR- Transcendence
Case 1: Course A

Course A is designed to have a supportive learning environment that allow students to develop skills to learn and attain the highest level of conative taxonomy which is transcendence (TR). The course was designed with the aim to introduce students to engineering knowledge and profession as well as developing their skills towards becoming future engineers. Students work in teams to propose an engineering-based solution to a sustainability-related problem using a systematic process with Cooperative Learning principles used to guide students to learn in teams. The problem was crafted in a real world setting and divided into three stages: (i) understanding problem, (ii) collecting data and (iii) finding engineering solution. In each stage, students were guided using the Cooperative Problem-based Learning framework as a scaffolding (Mohd-Yusof et al., 2016). Students received regular feedback from peers in their team and the whole class, as well as guidance from instructors, which helps them to continually improve their understanding and develop their skills as they move towards completing each stage. Students claimed that learning in this environment is hard at the beginning, but they manage to overcome the difficulties after gaining supports from the community-centred learning environment.

From the analysis of the observation data, students in course A work in their respective teams the whole semester, allowing them to attain a sense of belonging and bonding with their teams and classmates and become accountable and responsible to complete the task. This was also evident from the themes on “willingness”, “expedite”, “natural tendency” and “enthusiasm” that came up from the thematic analysis as shown in Table 5. This is also supported by Kerkela (2015) that the social support creates long-term behavioural change especially in students’ conation. Students who went through this effective social interaction have the natural tendency to do work, willingness to do the task and enthusiastic in every work. In the course, students learned through peer teaching, which trained them to explain, guide and lead others to gain a meaningful experience. Through the learning process, respondents stated that learning in this course helps them to get prepared for other courses (life-long learning), thus reaching the highest level of conative taxonomy which is transcendence as they feel satisfied, enjoy and gain meaningful experiences (TR) throughout the course. As stated by respondent RA2:

“I really enjoyed the learning process. In this course, like.. before and after the group discussion, the group assessment, presentation., is was all fun. Yes, it is really hard., but, doing it with your friend, make it really fun,.. and how to say,.. it is a memory for us. Like, when we are going to have our last presentation, during the last day of class., I can’t believe that this is the last class. I tell my teammates “remember the first stage we do always complaint, when this is going to be finish? When it will be finish?? and when the day comes, I can’t believe that this is our last class”. We feel sad and we miss all the crazy things, the hard things we do together.”

The implementation of cooperative problem-based learning encourages questioning, exploration and exposure to the real-world situation as it can nurture students’ competence, self-efficacy and autonomy to attained high conation (Lumsden, 1994, Huitt and Cain, 2005). The supportive classroom environment stimulates every member to felt valued and gain the benefit towards creating a high degree of conation to learn (Lumsden, 1994). Students who attained high levels of conation becomes completely immersed with the task. The transcendence level was described as a peak experience, joyous and mastery of the knowledge (Huitt and Cain, 2005).

Case 2: Course B

The course aims to introduce students with the responsibilities of an engineer and suggests a sustainable solution to the environment and mankind. In course B, students were supported in their transition to university a few times in the semester with in-class activities, field trip and industrial talk though it was not stated in course information. Students were given a project-based assessment that require them to complete a project formulation and management in a
group of multidisciplinary students. At the end of the course, students have attained the level of engagement and involvement. Students claimed that learning in this course is fun (IN) as they learned hands-on to complete a mini-project within their group as a community but they perceived a lack of support and guidance during the project. This was corroborated by the themes of “interest”, “impressed” and “excited” as shown in Table 5.

During project formulation and management, a general overview was given. Although students were asked about their groups’ progress no action was taken towards preparing students to manage the project in a big group. Non-specific feedbacks were given to students during the middle and end of semester, leading them to have trouble in applying their knowledge in completing the project and sometimes were unclear with the task given. Tamim and Grant (2011) stated that the theoretical guidelines of project-based learning required that students need to be monitored, scaffold, coach and guide continuously in collaborative learning. Grant and Hill (2006) suggested that students must have proper feedback and reflections on their learning experience as they moved through every phase of the project. Instructor should stress out the importance of regular feedback, solution review, whole class discussion, weekly report using formative assessment (Barron and Hammond, 2010).

Students claimed that learning in a big group of 15 to 20 people discouraged them from having effective groupwork since they felt no sense of belonging while completing the group project. A bigger group lets some members disengage with the task and neglected to do work. This problem makes them unprepared (EN), stuck and slow in taking actions, causing some of the respondents to be dissatisfied with their project outcomes. This was supported by the themes of “procrastinate”, “lack of basic knowledge” and “dependence” obtained from the thematic analysis (Table 5). Respondent RB4 claimed that:

“This course prepared us to work as an engineer in a social environment. It prepared us to work in a group. As an engineer, we have to work with people and need to understand our place in the system. I think this course really prepared me for that. But for my group, I can’t choose my group members and it is chosen by the lecturer. And if I were to choose, I will choose to work with 4-5 people for a group composition., Because when it has a large number of people in one group (15-20 students), there is like a social loafing, where people are thinking that the others is doing the work. But in the reality, everyone is not doing the work. When there is a lot of people, we do not know if there is any progress because of the lack of communication. We do not know who is doing the particular task. At the end, when we realised that no one is doing that task, it was already too late.”

Students needed support to manage the project in a large group and improve the engagement (Tamim and Grant, 2011). Students also needs clear expectations about the project requirement and a proper instruction. It is important to create a teaching and learning environment to ensure students becomes responsible with their own learning, helps one another, improve their mistakes and attain mastery (conation) on the knowledge pursued (Meyer et al., 1997).

Case 3: Course C

This course used a seminar-type approach, with a large number of students (120 in one class). The course aims to introduce various sub-disciplines in an engineering field. To do this, instructors were rotated according to their expertise every week to talk about the topics that have been assigned. The weekly change of instructors leads to no engagement, bonding and attention between instructors and students, which makes them not satisfied (FC) during learning process. Based on the analysis in Table 5, students attained the level of focus (FC) where students are able to bring information to a clear relief/picture. The thematic analysis shows the themes of “low engagement”, “no attention” and “separation of knowledge” occurred in this environment.

In this environment, instructors were the information provider, leaving students to passively receive information (Huba and Freed, 2000). Students primarily depended on the acquisition
of knowledge in a passive manner, which will obstruct students’ self-development, self-competencies and personal growth (Gerlach, 2008, Lak et al., 2017). Respondents stated that it is hard to pay attention, and the changes of instructors made them feel awkward to ask questions. Different instructors bring different teaching approaches and it caused the respondents to choose, distinguish and separate the discipline of knowledge (FC) they preferred the most. Moreover, the environment in this course (mostly teacher-centered) left them feeling bored during the class. Respondent RC3 stated that:

“The course helps us to differentiate which discipline we have interest on. As for me, I like structural engineering the most. When I got into the class (structural topic), I have the encouragement to set that “Yes this is where I am, I am going to choose this”. For others discipline, I don’t like hydraulic. I feel that it is really hard. So, I just leave it. And yes, the course helps to give us a clear picture of what engineering is, but the enjoyment and satisfaction was not there. The lecturers were ok, but some of it were quite boring. I just attended the class for the sake of attendance.”

Overall Discussion and Conclusion

Comparing the learning environments in all three courses in terms of the HPL framework criteria, course A implemented all four criteria systematically, while course C is missing most criteria except for knowledge centred, and course B is somewhere in between with emphasis mostly on the knowledge centred aspect and average in the rest. Comparing the conation of students in the three courses from the analysis of the interviews, students in Course A attained the highest level of conative taxonomy (transcendence), while students in Course B attained the level of engagement and involvement, and Course C attained the level of focus. This shows that when the HPL criteria were met, the learning environment was effective in developing conation to the highest level. On the other hand, missing elements created a learning environment that detracts from developing students’ conation. Kuchi et al. (2003) stated that HPL, which embraces an active learning process, supports learning communities through culturally appropriate instruction to develop social learning and instils students’ self-directed learning and students’ conative level. This indicates that each HPL criteria plays a major role that could influence student’s self-development especially on their level of conation. This can be seen when students in Course B attained the lower level of conation compared to students in course A with the infusion of Cooperative Learning (CL) principles to guide the development of learning teams. Guidance for developing learning teams such as the CL principles were missing in course B, although the Instructor tried to create a supportive community. The multidisciplinary group which consists of 15-20 students is simply too large and became unmanageable without a proper approach. The missing assessment-centred element in Course B in the form of inadequate feedback also caused students to feel neglected and procrastinate to do work, slow in progress and lost in track. Students in Course C attained the level of focus because the design and the implementation of the course was focused only towards the knowledge centred aspect. Students claimed that they are clear about the information but did not feel satisfied and was bored while attending the class. The objective and learning environment of this 1-credit hour course need to be re-examined if students’ conation were desired to be develop.

From this study, it can be summarised that different teaching and learning environment influence the level of students’ conation. Students will continually improve themselves as they going through an effective teaching and learning environment (TLE). Students who were guided and supported with scaffolding-based activities, learn in supportive community, received regularly feedback from peer and instructor tends to feel accountable, responsible and struggle to improve themselves and do their best in task completion. Besides that, students who underwent learning environment that fulfils all the HPL framework criteria throughout the semester would gain satisfaction, enjoyment and meaningful experience. A learner and assessment centred environment will result in students receiving encouragement, supports and interest to overcome personal barriers as well as attaining skills and conative
behavioural strategies and finally, leading them to achieve the highest level of conative taxonomy. The development in conation is especially useful in encouraging positive behaviour that will undoubtedly be useful in supporting and retaining students in learning and becoming an engineer. Hence, consideration must be taken to design and implement an effective teaching and learning environment in courses to the highest levels of conation towards preparing them to become a successful engineer for future.

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Identity in practice: Examining personal identities of engineering graduates in the transition to the workplace

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Abstract: Despite ample research in professional identity development in engineering, there is a gap in the literature regarding how professional identities relates to the personal identities of individuals in these contexts. This paper examines literature on personal identity and uses findings from an interpretive phenomenological analysis (IPA) investigation on identity transitions of students as they enter the workplace. The findings, based on interviews with seven participants, highlight how the individuals felt an elevated sense of significance in relation to their personal identities when entering the workplace, but they also concealed moments of insecurity when performing their engineering roles. I discuss the importance of examining personal identity in engineering contexts, both in the interest of advancing psychological identity theory and in the aim of supporting outcomes related to personal identity.

When we think of students as a human form of capital, the view potentially restricts our intellectual terrain. We run the risk of limiting ourselves to questions about what students know or how they perform prescribed tasks. We lose sight of the notion that schools allow people to forge new selves (Hanson, 2014, p. 10).

The above quote from sociologist Chad Hanson (2014) captures an important insight as to why identity research is so critical in the context of engineering education and practice. As students are gaining core engineering competencies, they are also developing in their understandings of who they are. Such a notion has received substantial treatment in engineering education research. But in this paper, I contend that much of the focus on developing an understanding of engineering identity has been undergirded by interests in the health of the profession rather than in the personal identity of individuals on their own terms.

In the sections that follow, I review how professional identity has been examined by existing research in engineering education and then survey literature from psychology that depicts personal identity as a comprehensive, holistic construct. I then present findings, original to this paper, from my previous research on the individual experience of identity in the transition from engineering education to the workplace (Huff, 2014; Huff, Smith, Jesiek, Zoltowski, & Oakes, 2018). I conclude by discussing how these findings highlight the complex lived experience of identity that occurs in the formative processes of professional development.

Professional Identity in Engineering Education Research

Prior research on professional identity in engineering education research tends to examine how institutional structures shape a collective engineering identity. Such work illustrates how identity is constructed through sociocultural structures that shape individuals in engineering domains. For example, in her ethnographic research on gendered patterns of engineering workplaces, Faulkner (2000) framed engineering identity to be marked by a clear demarcation of the technical and social, noting how the professional identity of engineers tends to privilege technical features while excluding social elements that are, in fact, deeply intertwined with engineering work (Trevelyan, 2007). Research that examines identity from a sociocultural lens often aims to elucidate systemic explanations related to how individuals are marginalized against the powerful social forces that dominate the collective identity of engineers (e.g., Secules, Gupta, Elby, & Turpen, 2018; Tonso, 2006; Walden & Foor, 2008).
Prior research in engineering education has also examined engineering identity from the perspective of the student as it relates to their motivation to pursue an engineering career. Godwin, Potvin, Hazari, & Lock (2016) found that first-year engineering students' connection to math and physics subjects, as marked by their interest and by others' recognition, predicted their choice to major in an engineering discipline. Furthermore, Matusovich, Streveler, & Miller (2010) found that engineering students were motivated to complete their degrees when they found alignment between their degrees and their identities. These investigations and others (e.g., Patrick, Borrego, & Prybutok, 2016; Pierakkos, Beam, Constantz, Johri, & Anderson, 2009) study professional identity as oriented toward understanding how students might persist in their trajectories to becoming engineers.

Generally, extant literature in engineering identity tends to be buttressed by at least one of two motivations. Research related to sociocultural perspectives of how professional identity is framed by engineering structures highlights the problematic features connected with dominant images of what it means to be an engineer. Importantly, these studies illuminate how engineering institutions, via education or the workplace, can create environments that marginalize a number of individuals who do not align with the prototypical identity of what it means to be an engineer. Alternatively, research on professional identity that is focused on individual experience tends to view the achievement of a professional identity in engineering as a positive outcome and, conversely, leaving engineering as a negative outcome. And, indeed, it is in the best interest of the engineering profession to attract effective and competent individuals to the field and for broadening participation in engineering.

However, while such work on professional identity in engineering has developed important understandings related to the construct, they also contain critical gaps. First, the underlying interest of the research is conducted from the interest of advancing the profession itself—either through critiquing the dominant collective narratives of identity that define the profession or through supporting individual commitment to the profession. The body of research on identity in engineering tends to neglect the experience of personal identity on the terms of the individuals themselves. Furthermore, there is little understanding of how core forms of personal identity, beyond the scope of the profession, might interact with the individuals' professional identity in the engineering domain.

**Personal Identity in Psychological Research**

From a psychological perspective, the framing of identity is vast and contains a broad range of perspectives on how to understand and, accordingly, investigate the theoretical construct. Vignoles, Schwartz, & Luyckx (2012) conceptualize identity as involving "people's explicit and implicit responses to the question: 'Who are you?'" (p. 2). They maintain that identity researchers have been divided on if identity is understood as a personal, relational, or collective construct. In this section, I review key references related to the understanding of personal identity. I examine this particular framing of identity in order to highlight how the construct might be investigated within individuals in engineering contexts in ways that speak to their lived experiences of how they understand who they are.

Identity was understood as a personal phenomenon due to the contributions of Erik Erikson (1959) in his theory of psychosocial development. Specifically, he understood identity to be the central focus of an individual in the stage of adolescence, and that through this formative period, an individual would be oriented to define oneself in a consistent, unitary manner. Although other perspectives on identity later emerged to frame the construct as something that was more defined by social and contextual contexts (e.g., Holland, Lachicote, Skinner, & Cain, 2001; Tajfel & Turner, 1986), Eriksonian perspectives on identity that are oriented to the individual have persisted in psychological literature.

Building on Erikson's work, Marcia (1966) developed the concept of identity statuses as a way of recognizing how individuals engage with their identity through both commitment and exploration. Further, Kroger, Martinussen, and Marcia (2010) named three significant
dimensions of identity in which individuals interact with through commitment and exploration: vocation, ideology, and sexuality. Arnett (2004) also has built upon Erikson’s work by extending identity explorations to be the core feature of emerging adulthood, that is, the period following adolescence in which individuals are seeking to explore identities and achieve a sense of autonomy in relation to their social environment. Arnett further highlights that emerging adults are particularly attentive to exploring identity in relation to love and work. Thus, from an Eriksonian perspective, one’s identity in relation to their profession is understood to be a dimension of a global, personal identity. Furthermore, an individual’s goals in exploring an identity in relation to their profession are more related to understanding one’s global sense of identity rather than simply developing as a proficient professional.

However, while it is well recognized in theory on personal identity that individuals do, in part, shape their understandings of themselves through contexts such as that of their workplace domains, there is little research in psychology that examines how personal identity is integrated across multiple domains. One useful construct to considering how an individual’s core personal identity might interact with their professional identity is contextual identity integration, which “involves the fit of the multiple identity domains that individuals consider important to who they are, or are forced to deal with due to social-structural factors” (Syed & McLean, 2016, p. 111). Syed and McLean (2016) develop their general understanding of identity integration as a phenomenon that is connected to McAdams’s (2012) framing of narrative identity. Indeed, his Eriksonian perspective of identity is quite distinct from the previously discussed work of Marcia (1966) as it defines identity to be “an internalized and evolving story of the self, providing a person’s life with some semblance of unity, purpose, and meaning” (McAdams, 2012, p. 100). From such a perspective, an individual’s role in multiple contexts might be cohesively tied together through the narrative that they develop in order to unify how they enact identity in contextual domains.

In summary, psychological research on personal identity is oriented to considering the individual’s sense of self in a more global manner than professional identity alone. However, this does not mean that professional identity is trivial to an individual. On the contrary, this body of research also frames the formative processes of identity development in the professional domain as important to gaining insight into a broader picture of a core identity within an individual. Accordingly, the present study is anchored in the framing of identity as a personal construct, where the contexts of engineering education and the workplace inform global patterns of identity development, which in turn provide robust insight into key features of how engineers understand their role within the institutional structures of their profession. Throughout the findings, I reference core identity to mean features of identity that are particularly central to the individual who is experiencing their identity.

Research Questions and Methods

Based on the gap in our understanding of the personal identities of engineering students and engineers in the contexts of their professional domains, the present study is framed by the following research questions:

1) How do students psychologically experience personal identity trajectories of becoming engineers?

2) How do these individuals relate their professional identities to their core identities?

3) How do these identities develop in the transition to the workplace?

I investigated these research questions using interpretative phenomenological analysis (IPA), which is a qualitative research methodology that facilitates an in-depth examination of individual lived experience in relation to a certain phenomenon (Smith, Flowers, & Larkin, 2009; Huff, Smith, Jesiek, Zolowski, Graziano, & Oakes, 2014). Specifically, I interviewed seven participants who were set to graduate from degree programs in civil, electrical, and mechanical engineering from a large public institution in the United States. I conducted two interviews with each of these participants: once in the final month of their last academic term.
before graduation and once after they had been in their workplaces for two to three months. Three of these participants identified as men (pseudonyms Haden, Parker, and Warren) and four identified as women (pseudonyms Alice, Naomi, Rachel, and Trixie). All participants identified as White, East Asian, or South Asian, ethnic and racial backgrounds that are overrepresented in engineering education within the United States. Moreover, all participants had received job offers at the time of the first interview. The study was approved by both the Institutional Review Board offices of my institution and the participants’ institution.

I employed a semi-structured approach to interviewing the participants on both occasions, which is documented in my previous work (Huff, 2014; Huff et al., 2018). The goal of each interview session was to elicit how the participants understood their core identities, how they mentally modeled what it meant to be an engineer, and how they positioned their identities as engineering students or early-career engineers in relation to their core identities. Further details about the data collection procedures may be found elsewhere (Huff, 2014; Huff et al., 2018). I then analyzed the data for these interviews in line with the highest standards of IPA research, which involved making multiple analytical passes through a single case at a single time period (e.g., Parker at Time 1), annotating the descriptive content, linguistic features, conceptual insights, and finally, emergent psychological themes. I then organized all of the emergent themes into a robust set of findings for an individual at that particular point in time. Following these analytical procedures, I moved on to analyze the same individual at the second time period (e.g., Parker at Time 2) by employing the same procedures. I continued this case-based analysis for each participant before combining the individual findings into a set of collective findings. Thus, by undergoing analysis in ways that maximized the idiosyncratic voice of each participant, IPA allowed for me to provide in-depth insight in ways that were aligned with the theoretical construct of personal identity. Further detail for the analytical procedures of the present investigation are reported elsewhere (Huff et al., 2014).

Findings

In the transition from education to the workplace, the participants demonstrated two significant themes, that is, psychological patterns of how they experienced their personal identities in the context of their professional roles. First, they incorporated their engineering role with an increased salience in relation to how they understood their core identities. Second, amid this sense of elevated significance in the importance of their engineering role, they privately grappled with insecurity in how they, as holistic individuals, enacted their identities in a professional setting. In the subsections below, I narrate these two themes in ways that are grounded in the lived experience of the participants. Following this section, I discuss how examining identity through a lens that focuses on the experiences of the whole person allows us to see these two themes that are ostensibly in tension with one another.

Theme 1: Elevating the identity salience of the engineering role

As students, the participants understood their identities as engineers to be primarily related to their personal interests and their intellectual performances in their discipline-specific coursework. However, after they had entered the workplace, they came to understand their role as engineers as something that was elevated from what they had envisioned as students. As early-career engineers, they perceived their identities in the engineering domain to occupy a more grandiose significance in relation to their social environment than they had experienced as students. Furthermore, among the study participants, there was a particularly nuanced and gendered pattern that distinguished the ways in which the men and women participants experienced this change in their identities as engineers. The men participants embraced this newfound significance to understanding who they were as engineers, but the women participants had a mixed emotional response to this change in their identities. However, the women participants did connect, with a sense of sobriety, to the newfound responsibilities that accompanied their roles as engineers in the workplace. I organize the description of the present theme by presenting each gender group together.
Haden, a male civil engineering graduate who went to work in a traffic engineering firm, demonstrated this acute sense of elevating his identity as an engineer in the transition to the workplace. As a student, he held a somewhat skeptical perspective about the meaning of his education, believing it to be disconnected from engineering practice as it would be realized in the workplace: “I think college is more of a test of, like, can you learn and, like, do you know how to learn, and do you have the abilities to learn? And then out in the real world, you’ll actually be learning how to do it.” In order to perform efficiently in the courses that he deemed somewhat irrelevant to engineering practice, Haden approached homework with a goal of completion at the expense of gaining conceptual understanding. He envisioned that his identity as an engineer had not yet been achieved and managed his prescribed curricular activities in ways that he could sufficiently perform as a student.

However, at the time of the second interview, Haden came to understand his role as an engineer to be significantly more aligned with his global understanding of his personal identity. While Haden did not particularly feel his identity shift in a dramatic way, in the second interview, there was a clear significance in relation to his connection to engineering that was not present in the first interview. He elaborated on this elevated sense of identity that he felt as an engineer in the workplace, stating:

I just know more now what it is to be an engineer, I guess . . . There’s just more responsibility in engineering than when you’re at school, because in school . . . if you miss a homework assignment . . . you can still get an A in the class . . . And in engineering, it’s kind of different; the problems don’t go away unless you solve them, and even if you solve them, a new one will arise.

Thus, for Haden, problems that characterized his engineering career had changed from the performative exercises that he encountered as a student to problems of greater importance.

Likewise, the other two men participants came to elevate the importance of their identities as engineers in their respective transitions to the workplace. For example, although he had once sought to distance himself from other electrical engineering students that he viewed as socially awkward, when he entered the workplace, Warren sought to be deemed “credible” by other electrical engineers. Likewise, Parker reflected on his newfound sense of autonomy in executing his everyday tasks, contrasting it to his experiences as an engineering intern. The men participants perceived that their engineering roles had afforded them a career identity with purpose—both to themselves and to others around them. And they found an increased significance in their career identities as engineers upon entering their workplaces.

The women participants also demonstrated a similar yet nuanced shift in how they came to feel deeper significance in their identities as engineers. For example, Trixie, a civil engineering graduate, connected her identity as an engineering student to her individual interests in structures and in her intellectual performances in mathematics and science. Upon entering the workplace, Trixie her identity as an engineer with elevated responsibility:

I never thought I would ever have this much responsibility. . . Just to put my name on a document and sign off on it and know that if anything does go wrong, it’s completely my responsibility because my name’s the one on the document . . . no one else but me.

While Trixie described elsewhere in the second interview how she was uncomfortable with the new level of responsibility in the workplace, she came to take ownership of this responsibility in understanding who she was in the context of her profession. Thus, Trixie’s concept of her professional identity expanded from one centered only on interests and abilities to one that included her responsibility to stakeholders of her engineering work.

Similarly, Alice, another civil engineering graduate, also exhibited a pattern of elevating the importance of her identity as an engineer. As a civil engineering student, she tied her professional identity to her childhood interests and abilities in “science…, problem-solving
and making things.” But in her transition into the workplace, she began to feel a larger sense of responsibility through being an engineer. As she stated in the second interview, “I definitely have more responsibility in this job, and I have more long-term projects. . . . As opposed to my co-op that was always little two-week projects, little tiny sections, so I wouldn’t ever really get the big picture of a project.

As Alice transitioned to the workplace, her personal identity in being an engineer became larger than her own interests and abilities in problem-solving. Enacting her role as an engineer meant that she was responsible for work that other individuals in her environment considered to be meaningful.

Finally, Rachel and Naomi also showed similar patterns of feeling a sense of increased responsibility as they transitioned to the workplace. As mechanical engineering students, they had also connected their engineering identities to interests and abilities that they held before choosing to major in engineering. However, as they transitioned into the workplace, they came to more fully understand the responsibility of their engineering-selves, largely through a sense of ownership regarding products that they had helped to design. As concisely put by Naomi, “I’m not just making [an appliance], I’m making something that’s going to be an integral part of somebody’s house and home.”

The findings among the participants highlight a similar shift in the internal experience of identity for all participants. As they transitioned from educational programs to workplaces, the participants came to associate their identities as engineers with the image of bearing responsibility for those in their social environment, including among users of their work outputs and among their co-workers. For the men participants, the newfound sense of significance to their identities was accompanied by a shift in how central their engineering identities were to their core identities. And while the women participants recognized this newfound sense of responsibility in their engineering roles, they approached this expanded view of engineering with a sense of sobriety. Rather than focusing on their own personal sense of enhanced credibility, their identity descriptions focused on the critical influence their role would have on others around them.

**Theme 2: Hiding insecurities while performing the professional identity**

In spite of the participants’ more pronounced identities as engineers, all men participants and three of the four women participants also came to contend with insecurity about how they performed these identities in their workplaces. They sought to conceal these moments of insecurity from their co-workers and, thus, distance their personal sense of identity from their roles in workplaces as engineers. I begin exploring this pattern with the case of Naomi. At the time of her first interview, Naomi did not identify as a high-performing student but as one who had overcome adversity in obtaining her mechanical engineering degree. As she stated:

I did really bad on my first semester, and then up until last semester, I flipped it around . . . I feel that I found that . . . I feel . . . like I’ve gotten everything that I came to [the university] to get—like, as long as they give me my diploma (laugh)

As a student on the threshold of her graduation from a mechanical engineering program, Naomi envisioned herself as one who had accomplished a series of incremental steps toward her degree. As a student, the diploma signified to Naomi the conclusion of a journey that she had, with some difficulty, completed. Upon entering the workplace, however, Naomi began a new journey. And, in her second interview, she also related how she did not yet feel that she had the competence to offer her company:

I’m still at the point where I feel like I don’t have a whole lot to offer in terms of the workplace because I’m still learning everything and I am so new. So it’s uncomfortable for me to just know that I’m just walking up to someone who has no idea who I am, and just, like, [I feel like I’m saying], “I want this, but I have nothing to give you back” kind of thing. So, it’s just uncomfortable.
She further unpacked how this insecurity in her abilities as a new employee had affected her desire to meet with an individual in upper-level management when she sought to take on an international rotation in her next work assignment, noting how in this interaction she “just kind of [felt] like a nobody.” From these excerpts, Naomi felt like she did not have “a whole lot to offer in terms of the workplace” and extended this understanding of herself to cast her as a relative “nobody.” Even in the excerpts in which she voiced her insecurities, she used the second-person voice, possibly a mechanism to distance herself from the discomfort that she described. But her insecurity was a recognition that, in her engineering role, she would have expectations of competence to perform in the workplace. Accordingly, she sought to conceal situations where any appearance of incompetence could be seen by others. As she stated, “I think it’s still like you come in and you feel like you have something to prove, and you don’t want people to think that you don’t know what you’re doing or you don’t have this skill set.” Naomi’s case highlights the pervasive discomfort that early-career engineers may feel upon their initial entry into their workplaces. While it would be reasonable to expect new employees such as Naomi to be in a safe time of learning in the early stages of a career, it is during this time that one might feel heightened social pressure to perform a prototypical engineering identity and, thus, avoid healthy behaviors that could improve their workplace competence, such as voicing moments of uncertainty known to experienced co-workers.

Haden and Parker likewise expressed their desires to avoid the appearance of incompetence in the workplace. As engineering students, at the time of their first interviews, they varied in how secure they felt in relation to their professional identities. However, each of them noticeably shifted toward a more insecure posture toward their professional identities. Parker described how asking questions about employer’s work processes made him feel like a burden to his co-worker: “You just feel like you’re pulling those around you down because they have to take time out of their day to help you understand something that they seem to think is so trivial.” Likewise, Haden discussed the phenomenon of “hating to ask about the next task.” He juxtaposed his internal perception with the explicitly welcoming social cues of his workplace, stating, “So they’ve been very open to [him asking questions], but it still kind of just looms in the back of your head.” In both Parker and Haden’s cases, they would eventually overcome their fears about asking questions in order to gain necessary knowledge for accomplishing tasks. But seeking input from co-workers was preceded with a ruminative internal dialogue where they weighed the benefits of gaining necessary knowledge against the costs of feeling judged by their colleagues.

At the time of her second interview, Rachel gave voice to this tenuous moment that preceded the times that she might express her judgment in a professional setting:

I constantly push myself at work, to, you know, speak up, voice my opinion, because I don’t think I’m competent enough yet to say, “Okay, this is how I feel.” . . . I know no one’s is going to laugh at what I say, because that’s just not who they are, but I think in the back of my mind . . . that’s the worst scenario.

Rachel’s statement aligns with the sentiments of the other participants. Her description suggests a split sense of her global self, in which she is both “pushing” and being pushed. In the moments where she could be seen as incompetent in performing her identity, she became highly attentive to her internal state and to how she was being seen by others. Rachel’s experience illuminates the fraught nature of developing identity in the workplace. In order to be understood as an engineer, the participants needed to practice expressing their professional voice—through seeking specific input from others or through stating their judgment. However, it was also in these moments that they felt a salient threat to their identities as engineers. By verbally expressing themselves, they became highly self-conscious of how they could be deemed as incompetent by their colleagues. And indeed, this judgement incompetence was a question that they were engaging in asking of themselves. As put by Trixie, who reflected on the new phenomenon of signing documents as an early-career structural engineer: “I know it’s definitely flattering to know that they think we’re that
competent, but sometimes I'm just like, ‘Are we competent enough (laugh) to put our names on these documents (laugh)?!”

Discussion

The findings of the present investigation highlight the complexity of identity development in the transition from engineering degree programs to workplaces. The first theme, which describes how participants elevated the internal significance of their professional identity upon entry into the workplace, superficially seems in line with previous studies in engineering education on identity. As reviewed earlier, such research portrays the professional identity development of engineers as a positive outcome. And, indeed, the participants did shift in the understanding of the significance of who they were as engineers. While as students, they perceived their connection to engineering to be a feature of their interests and recognized abilities (Godwin et al., 2016; Matusovich et al., 2010), their entries into workplaces afforded them the opportunity to recognize their role to their social environment as something that was more significant than individual expressions of their interests.

For the men participants, the elevated salience of their professional identities (Theme 1) was welcomed as something that was positive for their perception of their core, personal identities. While the women participants did not approach this shift in identity with a negative valence, they did regard their newfound sense of significance with more sobriety than the men participants. This is also in line with literature that critiques the dominant masculine images of engineering in workplaces (Acker, 1990; Faulkner, 2000). It is possible that the men participants were able to access a form of privilege in being ascribed an elevated status through their entries into the workplace.

However, the pattern described by the first theme cannot be understood in isolation from the second theme, which depicts the hidden forms of insecurity that the participants felt in enacting their identities as engineers. On the surface, it might appear that these two themes stand in a strange juxtaposition to one another. The first theme suggests that becoming early-career engineers in the workplace afforded a newfound sense of importance to the participants in relation to their personal identities. But the second theme indicates that these same professional identities were regarded, through the emotional experiences of insecurity, as distant from the core identities of the participants. Although these patterns stand in tension with each other, I contend that the participants felt both an increased sense of significance in their personal identities through their engineering role and a profound sense of personal distance from this same professional role when they were expected to perform what was required of an engineer.

To make sense of these two patterns’ co-existence, I turn to literature on shame, that is, a profoundly painful emotion that occurs when an individual fails to meet real or perceived sociocultural expectations (Brown, 2006; Huff et al., 2019; Scheff, 2003; Tangney & Dearing, 2002). Shame is an emotion that occurs in a self-conscious state, where an individual is heightened in relation to how they are being observed by others, which is consistent with the accounts of the participants in their descriptions of feeling insecure in enacting their professional roles. They had established an internal and elevated sense of significance to their identities in the context of their roles as engineers. Yet, while elevated significance in personal identity might have brought some internal satisfaction to them, this increased importance also came with a cost. Performing the role of an engineer also became more important, and the possibility that they might fail to meet the felt expectations of others in their professional domain motivated the participants to conceal the normal questions that might be expected of early-career engineers. The behavioral response of hiding in response to shame is well-documented in previous literature (Tangney & Dearing, 2002; Scheff, 2006) and provides insight as to why the participants sought to conceal their insecurities in the workplace. As the significance of their identities increased through their roles as engineers, so also did the likelihood that these same identities would be threatened through any failed
performances of maintaining such an identity. Unfortunately, by concealing their uncertainty, they limited their moments where they could gain insight into their new roles as engineers.

Implications and Future Work

I note that the findings in the present study are most relevant to the particular context of individuals from overrepresented ethnic and racial backgrounds that come from large, public universities. Yet the findings bear transferrable implications for those in engineering education and workplaces. First, engineering educators can improve the transition to the workplace by providing authentic accounts of how learning is expected to continue once after one becomes an engineer. If the participants had been previously socialized to encounter moments of uncertainty in their career roles, they might have gained satisfaction from their elevated sense of identity while mitigating the threat that accompanied the expectations of their roles. Second, the present investigation opens up a considerable opportunity to further develop a shared understanding of the personal identity of engineering students and practicing engineers. In particular, while existing research in professional identity orients stakeholders to improve the health of the engineering profession, examining personal identity in education and workplace settings can orient stakeholders to cultivate outcomes that support individuals within engineering. For example, such investigations might examine the well-being of engineering students and practicing engineers in relation to their identities (Waterman, 2008) with implications that would support the overall psychological health of these individuals. We in engineering education research, who are positioned to understand the important link between professional contexts and domains of identity that are more central to individuals, have the opportunity to advance identity theory while also supporting the individual needs of our students.

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Access for All: Promoting Universal Design Thinking in a Rehabilitation Engineering Course

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Abstract: Service learning is a high impact practice that can greatly increase motivation and promote deep learning. We have developed a project-based Rehabilitation Engineering course that included both Biomedical Engineering and Mechanical Engineering students. Projects were supplied by local non-profit community partners (for example Special Olympics), and focused on developing products for people with mobility impairments. In addition to the projects, student assignments included reflection prompts, four hours of community service (two of which had to involve direct contact with people of different abilities), and a sensory deprivation experience to develop empathy. Qualitative evaluation of student responses showed that students were able to develop some aspects of design empathy and understood the importance of accessibility and universal design.

Introduction

Service learning is a pedagogy in which students achieve academic learning objectives by working on projects that address societal needs. To distinguish itself from community service, there should be a reflection component included as part of the experience (Jacoby, 1996; Tsang, 2000). Students gain an appreciation for the role they can play in society by reflecting on a variety of socioeconomic and ethical implications of their experience.

Reflective judgment (i.e., critical thinking) and associated skills are an important educational outcome for engineering students (Tsang, 2002). The development of these critical thinking skills enables the engineering undergraduate to develop a broader appreciation of concerns facing the engineering profession and the world. Traditionally, reflective judgment within engineering service learning has focused primarily on the social, political, and cultural impact of engineering and technology on society. Engineering Projects In Community Service (EPICS), a vertically-integrated, multidisciplinary service-learning program (Coyle et al., 1997), has expanded the use of critical thinking skills to include reflections on the community partner (called the project partner), team dynamics, the design process, and ethics (Slivovsky et al., 2003, 2004).

Service learning and community-based learning have long been recognized as high impact practices (Kuh, 2008), and their benefits have been demonstrated in a number of different settings (Jacoby, 1996; Tsang, 2000). By participating in projects with a community-based focus, students gain an appreciation for the role they can play in society by reflecting on a variety of socioeconomic and ethical implications of their experience. Cal Poly has long had a strong design component in its engineering curriculum and stresses “learn by doing,” and this emphasis can be used in projects that can help the community.

Service learning pedagogy is seen in a variety of engineering and design classes. Early research on service learning in engineering focused on retention, diversity, and ABET outcomes, including both technical and professional skills (Bielefeldt, 2007). More recent work has shown that service learning design courses can result in improvements in
modelling and in metacognitive strategies (Lemons, et al, 2010; Lemons, et al, 2011). A survey of outcome assessments for project-based service learning show that it can improve creative design, knowledge, skills, and attitudes, and also improve specific outcomes such as cultural competency, ability to communicate effectively, and ability to function on multidisciplinary teams (Bielefeldt, 2007).

Many theoretical frameworks concerning service learning invoke experiential learning. Using this as a theoretical underpinning, Carver (1997) developed a conceptual framework for service learning, as shown in Figure 1. The student experience was described in terms of an ABC model – agency, belonging, and competence. In the figure, we have added the specific design competencies we hoped to encourage in our course: Universal Design and Empathy in Engineering, which will be discussed later.

**Figure 1. Model of Service Learning, modified from Carver**

Carver argues that the student experience should provide them with the opportunity to develop personal agency. They should recognize that they can become change agents within their communities, and hopefully develop a sense of belonging within that community. This sense of belonging should also be shared among students, faculty and staff. The third facet of the ABC model is competence, which might involve a number of different areas including cognitive, manufacturing, and social. In our current study, we will further examine student development in universal design and empathy.

The faculty must support the student learning experience through both program and setting characteristics (upper boxes in Figure 1). The program characteristics include providing multiple forms of active learning, authentic activities and assignments, a focus on drawing upon prior student knowledge and experiences, and promoting connection to future experiences and opportunities. In our current study, the program refers to the course and in
particular to the final project assignment, which was to design a device to assist a person with a disability (or an organization that serves those with disabilities).

The characteristics of the setting revolve around resources, behaviours, and values. Beyond the typical engineering resources of funds, physical materials, and access to manufacturing equipment, resources include trust, reputation, authority, and knowledge. The identification, selection, and use of these resources reflects the behaviours in the setting. Finally, the guiding principles that govern these behaviours make up the values of the setting.

Our implementation of service learning will involve people with disabilities. People with disabilities constitute a minority group within society, and as such are stigmatized in a similar way to other social minority groups (Barg, 2010). Many people with disabilities can become marginalized through prejudice, stereotyping, and discrimination (Martin, 2013). As this may be the first time that many of the students deal with people who have disabilities, we provide initial “Disability Etiquette” training, and we hope that the project-based course will help students think about issues of diversity and inclusivity on a broad scale. By focusing on user-centered design in our class, the client is an important participant in the entire design process; and students will have to think deeply about the different abilities of the end-user.

Throughout the course, we also stress universal design, defined as “The design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design.” This is our first Targeted Design Competency listed in Figure 1. Although we also discuss Accessible (or Barrier-Free) Design as well as Inclusive Design, the Universal Design strategies are well established and have seven guiding principles:

1. The design is useful and marketable to people with diverse abilities.
2. The design accommodates a wide range of individual preferences and abilities.
3. Use of the design is easy to understand, regardless of the user’s experience, knowledge, language skills, or current concentration level.
4. The design communicates necessary information effectively to the user, regardless of ambient conditions or the user’s sensory abilities.
5. The design minimizes hazards and the adverse consequences of accidental or unintended actions.
6. The design can be used efficiently and comfortably and with a minimum of fatigue.
7. Appropriate size and space is provided for approach, reach, manipulation, and use regardless of user’s body size, posture, or mobility.

Our second Targeted Design Competency involves Empathy in Design. This is an emerging area in engineering educational research, and a recent study has developed a conceptual model of empathy in engineering (Walther, et al 2017). They frame empathy as having three mutually dependent components: a skill, a practice orientation, and a professional way of being. They argue that empathy is a learnable skill, and that a student must (1) be able to “share the emotional state of the Other” (Affective Sharing), (2) project themselves into others internal world as if it were their own, without losing sense of self (Self and Other awareness), (3) take the perspective of others without extrapolating our own experiences (Perspective taking), (4) recognize and regulate our own emotions that result from interactions from others (Emotion regulation), and finally, (5) be able to switch between empathetic and analytic modes of thinking (Mode switching).

The practice orientation dimension controls how we act when applying empathy during practice. It requires students to (1) value stakeholders and end-users as important resources (Epistemological openness), (2) be aware of design implications and interaction on both a
small local scale and a larger systems level (Micro to macro focus), (3) be aware of critical ethical issues (Reflective values awareness), and (4) be aware of the many different values and constraints affecting engineering decisions (Values pluralism).

Finally, a professional way of being suggests that students: (1) reconsider how all stakeholders are impacted by engineering, including issues of equity (Service to Society), (2) must have a core belief in the “the dignity and worth of people and natural environment (Dignity and worth of all stakeholders), and (3) not only focus on analysis and objectivity prevalent in engineering studies but also develop empathy and emotional intelligence (Engineers as whole professionals).

Context

At Cal Poly we have developed an upper-level Rehabilitation Engineering course that targets Mechanical (ME) and Biomedical Engineering (BMED) students. The course has three 50-minute lectures and one three-hour laboratory each week over a 10 week term. Nineteen students took the class during its first offering, 16 ME and 3 BMED. The course learning objectives were:

1. Describe how different disabilities affect activities of everyday life.
2. Explain how the ADA and standards in assistive technology have improved the lives of those with disabilities.
3. Compare and contrast the principles of universal design with those of the traditional design process.
4. Design or re-design a device to help a person with a disability perform an activity of daily life, a work place function, or a recreational activity.
5. Analyze adapted designs for functionality, adaptability, and function.

The primary deliverable for the course was a final project, where students served a community partner and were required to design, build, and test a product (LO #4). The community partners were Special Olympics, our university’s Disability Resource Center, and Jack’s Helping Hand (https://www.jackshelpinghand.org/). Projects were (1) a bowling ramp for athletes in wheelchairs, (2) an awards stand so that Special Olympics athletes who use wheelchairs can travel to the different place levels, (3) an ADA-compliant wheelchair ramp that would allow athletes to get onto a horse, (4) an adapted surfboard to help a teen with a brain injury and major mobility impairment enjoy surfing, (5) an adaptive toy car to provide sensory stimulation to children with developmental delays, (6) a submersible platform to allow children with mobility impairments receive aquatic therapy, and (7) an adjustable and transportable laptop desk and stand for a wheelchair user.

In addition to the projects, student assignments included completing a (dis)Ability Awareness Survey, two sets of reflection prompts, four hours of community service (two of which had to involve direct contact with people of different abilities), a sensory deprivation experience to develop empathy (also with reflection prompts), and a motion analysis laboratory. There were also a number of guest speakers, including a panel of participants with disabilities, a representative from the Disability Resource Center, a local Certified Prosthetist & Orthotist, and an expert on the American with Disabilities Act.

The Sensory Deprivation Laboratory was borrowed from the Kinesiology Department course on Adapted Physical Activity. After appropriate training and discussions on being respectful of those who have the disabilities covered in the lab, pairs of students used a wheelchair (second student observed both the wheelchair user and how others treated them). A second exercise was conducted with students blindfolded and using a white cane. Each student had the opportunity to participate as observers/assistants and as participants. Several prompts were supplied afterwards to develop empathy, to have students discuss access as it relates to the ecological perspective on disability, and to brainstorm on different engineering design
ideas that might be used to help people with disabilities navigate our campus. (It should be noted that future iterations of the course will modify this lab so that it does not seem like students are “trying on” a disability. Students will use either crutches or scooters, and possibly be led on a tour by someone with a visual impairment to help develop empathy).

Research Questions
1. How did participation in the course affect student attitudes towards people with disabilities?
2. To what extent did the course help students develop empathy?
3. To what extent did the course promote design thinking?

Methods
Before students took the (dis)Ability Awareness Survey, they signed an Informed Consent Document to participate in the study. Although the results from the survey did not indicate any change in attitudes towards people with disabilities before and after the course, we are still validating the survey with a larger population and will report results elsewhere. The remaining analysis will focus on reflection prompts that were part of the course assignments.

We will apply a qualitative research approach to analyse the responses to reflections during the course. This will be a general inductive approach” (Bryman and Burgess, 1994; Dey, 1993), which allows research findings to emerge from the frequent or significant themes inherent in the reflections, without the restraints imposed by more structured methodologies. By using this method, we can also identify any significant unplanned or unanticipated effects or side effects arising from course implementation (Thomas, 2006).

The first reflection prompt was after the students completed the Sensory Deprivation Lab. Here we will focus on the first prompt, which was:

How would your life change if you had to live permanently with each of the disabilities included in this exercise? Use specific examples from your experiences during class, lab and the sensory deprivation exercises but do not limit yourself to just discussing your sensory deprivation activities; integrate theory from your text and readings where possible.

The second reflection was after the students completed their required service hours. They had to complete at least four hours of service, two of which had to be in direct contact with people who had a disability. The prompt for this reflection was:

After your service experience, write a minimum of 500 words answering 3 or more of the following prompts. Write in a narrative style, in cohesive paragraphs (eg, don’t just answer the question under each line).

- Did the experience contradict or reinforce class material?
- How did course material help you overcome obstacles or dilemmas in the service experience?
- What similarities do you share with the people you are serving? What differences?
- What are their strengths? What can you learn from them and their strengths?
- What stereotypes are you confronting about the people you serve? Have you reconceptualized these stereotypes? What new information lead you to do this?
- How has your orientation to or opinion about this issue changed through this experience?
- Do you have any ideas on how rehabilitation engineering might help clients meet their goals?
The final prompt was at the very end of the course and involved shorter answers to several questions. For this research, we are focusing on the prompt:

- *Has the class changed your ideas about design? If so, in what ways? If not, what could be done better to discuss design?*

**Results**

The Sensory Deprivation Lab was conducted during Week 4 of the class, and the primary prompt was "How would your life change if you had to live permanently with each of the disabilities included in this exercise?" The prompt also defined life changes:

Life Changes: reliance upon others; emotional impact; the potential to use technology; modifications to car, house, etc.; time lines; the need for PFP; health insurance issues; employment opportunities; quality of life & recreation activities. Practical beyond campus, daily living tasks; inside buildings; grocery stores; keep moving to avoid sores; standing to reduce risk of infection; ecological model - disability is social construct & belongs to the physical environment.

Most students focused on the physical limitations that might be encountered should they use a wheelchair or have low vision, while only a few discussed potential emotional and social ramifications. Primary themes that evolved were (1) longer times in transit (e.g., between classes), (2) physical energy required to push a manual wheelchair around our hilly campus, (3) the extreme disorientation when blindfolded, (4) limitations of the environment, (5) issues of autonomy, (6) limits on recreation and exercising, and (7) the way others treated them during the exercise.

Some of the responses included:

- *Now I feel more conscientious about my surroundings, and will hopefully be able to incorporate this into future projects*
- *Although some people were very nice and helpful, others felt awkward around us and were not sure how to act.*
- *Living with a disability such as the ones experienced in this lab would undeniably alter my life, however with the assistive technology today, I think of it more as a challenge, rather than a disability.*
- *Students were overly ambitious to help which took away some of my independence.*
- *The blindness was more of a mental challenge while the wheelchair was a physical challenge*

The lab participants did notice a number accessibility issues, including difficulty opening doors, locating elevators and stairs, and cracks or discontinuities in sidewalks that disrupted both the wheelchair use and the white cane.

After performing their volunteer service hours, students were asked to reflect on their experiences. The majority of the students volunteered with Special Olympics, and nearly every student commented on the smiles of the athletes, their joy of the games, and their comradery. The responses weren’t conducive to additional thematic analysis. Comments included:

- *Looking back on this event, I’ve never been in an environment where there has been so much enthusiasm and encouragement to compete regardless of the obstacle that lays ahead. I look forward to volunteering at Special Olympics in the future.*
- *I almost feel embarrassed that I thought it might be an awkward experience.*
- *This experience reinforced what we have been saying in class. One thing is that disability does not mean a poor quality of life*
In the final prompt, the majority of students responded that their thoughts on design had changed after taking the course. Interestingly, some of the students had already begun their capstone design projects and were very familiar with the design process, while other (mostly third year) had never really done a project-based course. Three primary themes in the responses were noted: (1) the principle of Universal Design, (2) the wide variety of assistive devices available, and (3) the overall design process and the iterative nature of design.

Some responses showed nuanced design thinking:

- In this class, I found myself considering more about how I interact with my environment, and how this differs from how others may interact with theirs.
- From now on, I will probably always analyze products and structures and ask myself who they were designed for.
- Now I understand and appreciate the diverse types of design, such as universal design, niche design, and individual design.

Another respondent recognized the importance of universal design, but commented that:

- However, individual design can be extremely rewarding. By designing for an individual, one life can be made drastically better just because their needs are being focused on instead of generalized.

This student went on to say that

- The way that engineering impacts lives, as taught in this class, is the core of why I wanted to become and engineer in the first place. I don't just want to 'design', I want to design with a purpose.

**Discussion**

The course structure allowed us to develop an experience for the student that promoted agency, helped develop design competence, and promoted a sense of belonging. Overall, the students designed successful products and were able to use an empathetic design approach where they interacted with primary stakeholders (the students and their designs are shown in Figure 2). The sensory deprivation lab was a meaningful learning experience for the students, but it can be difficult to separate empathy from sympathy, or even sometimes pity. Recently, we have decided that it is not appropriate for students to just “try on” a disability - and we are cognizant that people with disabilities may not appreciate our attempt at using their assistive technology as a laboratory experience.

Many of the students in the class had not interacted much with people with disabilities until their service activity. Volunteering with Special Olympics was a positive experience for everyone, and students commented that they easily overcame any initial apprehension that they may have felt. Several also mentioned that the “Disability Etiquette” presentation at the beginning of the course prepared them well for dealing with the athletes, coaches, and family members. Students were also able to interact with several members of the community during a panel session, and were introduced to different assistive technology devices as well.

Students exhibited development in several of the areas in Walther's Empathy model, particularly in the professional way of being component. The focus on Rehabilitation Engineering provided one primary aspect of equity, although future course offerings could look at other intersectional issues of equity. Some formed attachments to their clients and their projects, and to the athletes during their volunteer activities, addressing the Engineers as whole professionals portion of the model. Additionally, their reflections indicated that they had developed an appreciation for the dignity and worth of all stakeholders.
Figure 2. Final design projects, from left to right: computer desk stand, bowling ramp, adapted surf board, ramp for equestrian access (in back), adapted toy car, aquatic therapy platform, Special Olympics award stand.

Because of the short term nature of the projects (five weeks), students were not able to fully develop in the other two components of the empathy model. Because they only met with stakeholders a few times, they only had limited opportunity for values pluralism and epistemological openness. Beyond accessibility, there wasn’t much growth in terms of reflective values awareness, and no true opportunity to reflect on micro to macro focus.

The course did offer some opportunities for growth in the skills component. They were provided opportunities for Affective Sharing, and some may have taken the additional step of Self and Other awareness. It is less clear if students were successful in Perspective taking, Emotion regulation, or modes switching.

This was one of the first complete design experiences for most of the students. They had to consider budget, project planning, stakeholder input, manufacturing skills, and the iterative nature of design. In their final reflections, the majority of students mentioned universal design and greater consideration for a range of abilities in their future designs. The course was able to create a learning environment that supported Carver’s model, creating a sense of agency in the students, stronger ties to their community and to each other (belonging), and design competencies that they can take into their future capstone courses or engineering careers.

It should be noted that there may have been some inherent bias in the student reflections, because students knew their work was being assessed as part of their grade. Although students were given instructions to be open and honest in their answers, and that the assessment was based on truthful, thoughtful treatment of the prompts, some may have simply tried to reply on what they thought the instructor “wanted to hear”.

Conclusions and Recommendations

In general students met our course objectives, exhibited engineering empathy, and appreciated the principles of universal design. In future offerings of the course, we plan to start the final projects sooner in the quarter to provide students the opportunity to refine and improve upon their initial designs. We will need to be more intentional in both our course assignments as well as our research design to fully explore how well the students achieve the components in Walther’s Empathy in Design. This will include assessments not tied to the course grade, such as anonymous surveys, focus groups, and interviews.
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Constructing the Bourdieusian field of engineering education: Engineering education transformation as a field phenomena

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Abstract: We propose to express engineering education as a Bourdieusian field. For engineering education to be considered a field distinct from higher education, specific capital and specific logic for pursuing and gaining that capital needs identifying. Bourdieu suggests that information on capital and specific logic of a field can be obtained through observing the trajectory of that field. In this research, the trajectory was the recent historical transformation of engineering education. Drawing from documentation of engineering education changes over the period 1980-present, we give evidence that engineering education is a field with specific capital, informed by and responding to industry, with implicit rules. We argue that viewing engineering education as field allows for exposure of the positions of engineering education participants related to their capital or power. This exposure facilitates analysis of issues of practice in engineering education.

Keywords: Bourdieu, field, transformation

Introduction

Engineering education research quality- the role of theory

Qualitative approaches in educational research include established methods of data collection and analysis selected on the basis of articulated theoretical and epistemological positing of research design. Engineering education research (EER) has emerged and rapidly evolved as a discipline only relatively recently (Jesiek, Newswander, & Borrego, 2009; Lohman, 2008) with global capacity in EER fostered through initiatives supporting development of a collaborative, internationally connected EER community (Williams & Wankat, 2016). Unlike well-established educational research, which had clear foundations in relevant theory, theoretical perspectives (learning, social, psychological and pedagogical theory) and linkages to research design were often found to be missing in early EER (Streveler & Smith, 2006). The maturation of EER has also seen researchers grapple with the scientific authority of quantitative and statistical methods "which can provide an aura of trustworthiness" (Koro ljungberg & Douglas, 2008, p. 172). Geographically aligned methodological differences in educational research approaches can both compound and inform the definition of EER quality (Borrego and Bernhard, 2011). In the US, the method driven research tradition is evidenced by a paucity of qualitative research, and the trend for publishing empirically evidenced research (Borrego & Bernhard, 2011; Koro ljungberg & Douglas, 2008). It maybe supposed that this early 2000's paucity is now reversed; yet as recently as 2014, despite an increasing number of qualitative research papers submitted to JEE, a high number were rejected (Baillie & Douglas, 2014). Baillie & Douglas (2014) suggested the juxtaposition of engineering and social sciences research cultures contribute to confusion over how to assess quality of engineering education research and, in the case
of JEE, leads to the rejection of research which does not conform to an engineering culture of positivism.

In order to enhance the quality of qualitative research Baillie and Douglas (2014, p. 6) exhort researchers to move beyond a thematic analysis and “include the epistemological stance taken, the methodology and methods used, the role of theory, and the relationships among all of these". In a similar vein, EE researchers call for explicit and consistent application and articulation of the theoretical perspective for quality in EER (Borrego & Bernhard, 2011; Borrego, Douglas, & Amelink, 2009; Case & Light, 2011). The well-argued need for a theoretical position to inform EER design and practice led the first author to an exploration of relevant theoretical perspectives in their doctoral research.

Bourdieu’s social theory of practice

One such relevant social theoretical perspective, the ‘theory of practice’, by French sociologist Pierre Bourdieu (Bourdieu, 1977) has been used and continues to be useful in education research (Grenfell & James, 2003; Murphy & Costa, 2016). In addition, Bourdieu himself undertook research in education (Bourdieu, 1988; Bourdieu & Passeron, 1990). The theory of practice has three core concepts; field, capital and habitus that are introduced briefly here, before proceeding to focus on field for this discussion. Explaining the theory of practice, Bourdieu refers to a field as a social arena of practice characterised by specific capital (that thing of value) and specific logic (rules) to obtain that capital, where agents try to acquire capital by playing by the rules of the field, bringing to the field their own habitus (learned behaviour) (Bourdieu, 1990). Bourdieu also refers to field “[a]s a space of potential and active forces” and as a site of conflict or struggle; where agents compete to transform or preserve the configuration of these forces (Bourdieu & Wacquant, 1992, p. 101). The other concepts of capital and habitus can be understood through the following authors’ interpretations:

"Anything may count as capital that is afforded, however tacitly, an exchange value in a given field, and thereby serves both as a resource for action and as a “good” to be sought after and accumulated. The implication of this is that forms of capital are multiple; each field defines its own species of capital." (Crossley, 2001, p. 87)

"Simply put, habitus focuses on our ways of acting, feeling, thinking and being. It captures how we carry within us our history, how we bring this history into our present circumstances, and how we then make choices to act in certain ways and not others." (Grenfell, 2008, p. 52)

What is of interest in this paper is Bourdieu’s demonstration of the composition of the field (the structure of the field) which is defined by the objective positions that agents (actors, participants) can take in the field (Bourdieu, 1993). The positions depend on different kinds of capital that are active and recognised by the field (Grenfell, 2008).

Mendoza, Kuntz, and Berger (2012) succinctly explain Bourdieu’s (sometimes inconsistent) positioning of education as a field, a competitive arena with varying, relative positions of participants, including academics, determined by academic, scientific and intellectual capital. Academics’ shared understanding of norms, or habitus, is informed by socialisation and habitus is in turn shaped by access to capital and shapes capital: “Capital and habitus come into play within a specific field, because that field and its specific logic dictates in what ways different amounts and types of capital can be used for competitive advantage.”(Mendoza et al., 2012, p. 560)

Bourdieu’s theory of practice and engineering education research

The three concepts of field, capital and habitus, have been used sparingly in engineering education research, for example, Devine (2012) used the notion of habitus to understand students’ behaviour whilst Kloo & Rouvrais (2017) used field and capital to help explain the South African context of engineering education. Mendoza et al. (2012) argued against Delanty’s (2001) criticism that Bourdieu’s theoretical framework was inadequate to deal with
complexities of contemporary academic capitalism (evidenced by commercialisation, industry-academia collaborations and funding, spin offs and patents) by applying concepts of strategy and habitus. Very few others have used all three concepts of field, capital and habitus, and the secondary concepts that developed from them such as conflict or competition and strategy (Jolly, 2016; Kloot, 2011).

Proposing engineering education as a field

While previous studies have applied Bourdieu’s concepts in EER and some (Jolly, 2016; Kloot, 2011) have tried to establish the field of engineering education, a challenge seems to be differentiating the capital and specific logic (implicit rules) that are unique to the field from its influencing fields of higher education and industry. This paper proposes to construct engineering education as a field with specific capital and specific logic.

Research questions

In order to construct engineering education as field distinct from higher education, two research questions are therefore posed:

- What is the specific capital of engineering education?
- What is the specific logic around pursuing that capital?

The capital and logic of the field can be understood by observing occurrences in the field, which is, what the main actors within it are doing, and how they are doing what they do. These occurrences can be obtained from the trajectory of that field, which is best observed through the changes or transformations that have occurred in a field (Grenfell, 2008; Kloot, 2011). The aim is to establish the existence of specific capital and the specific logic associated with engineering education, opening up the prospect for using Bourdiesian concepts of field, capital, and habitus to provide a theoretically grounded interpretation of issues of engineering education that are related to socio-political contexts such as the current doctoral research study of the first author.

The doctoral study explores the argument that the existing discourse on developing global engineers is founded on the Global North perspective of what engineering education is. The abundant literature available on globalisation of engineers does not speak from the reality of engineering education that exists in most Africa countries, although it contains a few contributions from Africa. Using Tanzania as a case of Africa, the doctoral study seeks to contribute an African perspective of engineering education, analysing challenges and opportunities of adapting the existing discourse to the context. A critical review of literature, undertaken for the doctoral research, found that intertwined issues of globalisation and accreditation embedded in engineering education are subject to power inequities and struggle in the African context in relation to the Global North where the discourse originates (Matemba & Lloyd, 2017). This highlighted the need to expose the structure of engineering education and an exploration of Bourdieu’s theory for sense-making of the doctoral research data and context.

Bourdiesian notion of field

It is useful to consider a field as a hierarchical system that recognises some objective positions that agents and institutions can take up according to the amount and type of capital they possess (Naidoo, 2004; Webb, Schirato, & Danaher, 2002). For example the higher education field recognises, establishes and maintains hierarchies of academic positions; professors, senior lecturer, assistant lecturer and tutor. Each of those positions in the university is defined and attained by the amount of capital; such as contribution to and profile in the profession and discipline (intellectual capital), record of research and publications (scientific capital), and the generation and control of teaching, research and financial resources (academic capital). The university and departmental organizational fields also reward those positions in different ways and academics strategize to attain those positions.
by following rules of the field or its specific logic, such as by acquiring a PhD and research
grants, publishing in particular journals and increasing citations. Those positions however,
are not equal across intuitions although intuitions may have the same descriptors or titles of
positions; as Bourdieu and Wacquant (1992) explain- the positions are objective but also
relative:

*In analytic terms, a field may be defined as a network, or a configuration, of objective
relations between positions. And these positions are objectively defined, in their existence
and in the determinations they impose upon their occupants, agents or institutions, by their
present and potential situation (situs) in the structure of the distribution of species of power
(or capital) whose possession commands access to that specific profits that are at stake in
the field, as well as by their objective relation to other positions (domination, subordination,
homology, etc.).* (Bourdieu & Wacquant, 1992, p. 97)

For example, a professorial position at a small regional institution is not the same as one at a
large state university, or similarly, position differentials occur between research-intensive
and applied-research institutions of technology. This network of objective relations between
positions that Bourdieu and Wacquant (1992) talk about here, is what is significant in the
field notion. These positions are defined by what individuals need to do to access those
positions, and what tenants in those positions are expected to do. Also within a field there
are dominant capital (capital that is active in the field) and those who possess this play a
leading role in the functioning and transformation of the field:

*The principle of the dynamics of a field lies in the form of its structure and, in particular, in
the distance, the gaps, and the asymmetries between the various specific forces that
confront one another. The forces that are active in the field - and thus selected by the
analyst as pertinent because they produce the most relevant differences- are those which
define the specific capital.* (Bourdieu & Wacquant, 1992, p. 101)

**Methodology**

To address the research questions, the authors conducted desk research to seek the
occurrences in engineering education, which is, what the main actors within engineering
education are doing, and how they are doing it. These occurrences were obtained from the
trajectory (changes or transformations) of EE from the 1980s to the early 2000s, a period of
transformation in engineering education with significance to the Global North discourse of
engineering education and accreditation, and the emergence and evolution of EER.

Occurrences were obtained through a comprehensive exploration of literature on the
transformation, history, evolution, or development of engineering education. The literature
searched included journal and conference articles, discussion papers and editorials, and
documents from: EE specific journals including the Journal of Engineering Education,
and the Australasian Journal of Engineering Education; conference proceedings including
IEEE Frontiers conference and the Australasian Association of EE conferences; and
organisations’ documents including reports, accreditation criteria and guidelines (Engineers
Australia, American Society of Engineering Education, etc).

The literature was selected from the search if it informed or interpreted the trajectory of the
field, this included previous reviews of engineering education trends. Relevant references
found in the selected literature were also searched for and added to the data if they provided
additional information on trajectory phenomena. The literature was curated in the qualitative
research tool Nvivo11 and coded starting with concept-driven coding (Richards, 2009) where
data was coded into pre-set main categories of ‘capital’ and ‘logic’, and then moved to data-
driven coding where data in the main categories was coded iteratively to create sub-themes.
In the process two new categories ‘agents’ and ‘influence’ developed and were included in
explaining the field’s distinction. The data collection is currently ongoing until saturation is
reached, but the following are the developing findings.
The distinction of engineering education as a field

Engineering education agents

Engineering education under scrutiny in this research is higher education that focuses on training of engineers. In this area of practice we see people (individuals, organisations or institutions) such as academia, industry and professional community, involved because of their interest and stakeholder vestment in developing engineers - in particular, engineers who demonstrate the knowledge and attributes for entry to the profession (Sheppard, Colby, Macatangay, & Sullivan, 2006). In Bourdieu’s terms, engineers, professional bodies, accreditors and academics, may be defined as agents who participate in the field of engineering education.

The transformation literature shows that agents have debated about what should be taught, who should be taught and how it should be taught - curriculum and methods of teaching - and these debates have been significant in the trajectory of the field (Froyd, Wankat, & Smith, 2012; Seely, 1999). The debates in Bourdieu’s terms can explain that the field of engineering education contains agents who are contending to define what is capital and how to obtain that capital as they try to improve their own position. They also appear to be playing by some implicit rules or following a certain logic that the field is made up of, for example, adhering to accreditation, transforming to outcome-based education and engaging in EER.

Influence of higher education and industry on field

The training of engineers, through history, has come to a place where it sits within the academy (the university or polytechnic) but operates according to its own set of rules that are related to the acquisition of professional competencies. The acquisition of these professional competencies is variously defined as the purpose of engineering education: for instance, the Washington Accord, which is a multi-lateral agreement between bodies responsible for accreditation or recognition of tertiary-level engineering qualifications states:

…”the purpose of engineering education is to build a knowledge base and attributes to continue learning and to proceed to formative development that will develop the competencies required for independent practice (Froyd et al., 2012)

And the international initiative and community or practice in engineering education Conceive, Design Implement and Operate (CDIO) organisation state:

The purpose of engineering education is to provide the learning required by students to become successful engineers –technical expertise, social awareness, and a bias towards innovation (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014, p. 1)

Engineers Australia describe engineering education as the process of developing competencies that

…”represent the profession’s expression of the knowledge and skill base, engineering application abilities, and professional skills, values and attitudes that must be demonstrated at the point of entry to practice. (Engineers Australia, 2013, p. 4)

These definitions of purpose indicate that the engineering education field is influenced heavily by the profession, or industry. However, it can’t be fully free of the higher education field in which it operates (unless it reverts to the apprentice system akin to England in the 1880s) nor can it just submit to the rules and forms of capital operating within higher education either. This means in Bourdieu’s terms that the engineering education field has relative autonomy (Maton, 2005), that is, it has independence but also that independence is at times influenced by other powers as illustrated by professional body accreditation. The level of autonomy differs between contexts.
What is the specific capital of engineering education?

The literature on transformation of engineering education shows that since the 1980s there was a greater focus on graduate professional skills or competencies, starting with realisation of the lack of generic skills for graduate engineers (Dodridge, 1999). The EE generic competency discussions between the 1980s and the 1990s were motivated in part by engineers’ increasing mobility brought about by the opportunities of the global job market for engineers due to globalisation and technological revolutions (Ibrahim & Cockrum, 1993; Lucena, Downer, Jesiek, & Elber, 2008), and the predictions of their increase in the 21st century. This brought about an urgency for nations (mostly the Global North) to assure transferable skills for graduate engineers in a bid to retain their competitiveness in the global arena (Dodridge, 1999; Engineers Australia, 1996; Ibrahim & Cockrum, 1993; Lucena et al., 2008; Wulf, 1998). This also meant that they needed to identify those competencies which at the time were not clearly defined as they were not the focus of engineering education.

In the mid to the end of the 1990s there was increase in national debates about graduate competencies coupled with initiatives to transform engineering education and in 1995 the American accreditation organisation Accreditation Board for Engineering and Technology, ABET, introduced a set of competencies known as Engineering Criteria 2000 (EC-2000). Introduction of EC-2000 marked a milestone in engineering education as it resulted in the shift to competencies-based accreditation and later to outcomes-based engineering education, it also saw ABET transforming into a powerful stakeholder in the engineering education arena. ABET criteria, EC-2000, very quickly became international (Lucena et al., 2008; Prados, Peterson, & Lattuca, 2005) with American proponents trying to promote it in conferences, with other countries including it in their discussions as seen in the report by the Australian engineering professional body, ‘Engineers Australia – Changing the Culture’ (Engineers Australia, 1996). This drove transformation in engineering education curriculum to outcome-focused from content-focused.

Discussion progressed during the early 2000s as engineering education actors sought to define how competencies such as the ABET 2000 criteria could be taught and assessed (Besterfield-Sacre et al., 2000; Shauman & al, 2005). There were debates about the difficulty for engineering education to achieve the required competencies in their graduates accelerated by industry complaining that they were not receiving graduates that were ready to practice (work-ready) which led to more efforts in defining engineering competencies (Lohmann, Rollins, & Joseph Hoey, 2006). Also around this time some practitioners’ work reflected an effort to define generic competencies for graduates relative to their countries (King, 2008) while others tried to create a more global perspective (Allan & Chisholm, 2009); referring to the competencies as global skills or competencies for the 21st century or generic competencies (Male, Bush, & Chapman, 2011). These efforts were also well supported by the then developing engineering education research area (Jesiek et al., 2009; Lucena et al., 2008). This also led to reforms in accreditation systems including the Washington Accord which started using graduate attributes as an educational requirements in their accreditation standards from 2013 (IEA, n.d.) with accreditation bodies defining their standards in more detail as seen in Australia, when Engineers Australia produced more detailed sets of requirements in 2005 for entry to profession.

The focus of the debate has since developed into the current decade with industry transformations leading to increased discussions and efforts to re-define graduate competencies with a new focus on what contemporary engineers do, and how engineering education can build that expertise (Litzinger, Lattuca, Hadgraft, & Newstetter, 2011; Walther, Kellam, Sochacka, & Radcliffe, 2011). Engineering education researchers have been participating in these efforts by researching the role of engineers in the industry and society - how engineers practice their profession- and this focus on relevance to industry practice has allowed for the competencies capital to be more distinct.
Engineering education transformation phenomena shows that there is a developing shift in capital in engineering education catalysed by industry and their demand for engineering education to produce engineers that are relevant to industry – hence more push for the competencies capital. The focus on competencies of graduate engineers in relation to what engineers actually do (Trevelyan, 2010b) became more dynamic about a decade ago with concentration on the environment that engineers had to work which is now not only multidisciplinary but also multicultural due to globalisation. For example the issue of understanding the community and turning the importance of competencies such as intercultural teamwork and communication and knowledge of social issues became central (Chan & Fishbein, 2009). This focus, globalisation, seems to still be the current debate in engineering education either explicitly or implicitly (Jesiek, Zhu, Woo, Thompson, & Mazzurco, 2014; Male et al., 2011) reflecting the current job market. Hence the debate on competencies continues up to the most recent with the issues being closing the gap between graduate attributes and professional skills (Trevelyan, 2010a; J. Walther & Radcliffe, 2007).

What are the specific logic around pursuing that capital?

The observation of transformation activities also reveal a certain pattern to which changes are taking place in engineering education; for instance the collaboration among different actors such as engineering educators, professional bodies and higher education stakeholders in advocating changes. Also there were always activities such as debates, workshops, and some forms of working parties prior to every major transformation and a new agenda in transformation; for instance ABET criteria were promoted in national and international forums (Lucena et al., 2008). At all times since the introduction of competence-based accreditation in the 1990s professional and regulatory bodies described the standards – hence defining the capital and rules of the field through accreditation which then mobilised changes towards changing education, for instance, changing the curricula or teaching and learning. This pattern of accreditation can be interpreted as the specific logic of the field. These specific logic of the described field seem to be according to the context- geographical, economic or social- from which the trajectory belongs. The trajectory in discussion is across the Unites States, Australia, and sometimes Europe. For example, literature shows how important accreditation is to engineering institutions in signifying competencies and the efforts by the institution in those contexts strive to achieve accreditation of their programs.

The main logic of the field identified from the transformation literature apart from program accreditation is outcome-based education, and collaboration (involvement) of stakeholders (Engineers Australia, 1996). These seemed to be the assumed procedures in the field especially with regards to acquiring competencies capital. Program accreditation run by a professional body or an independent agency seemed to be an important rule, as the competencies were defined through accreditation for example ABET criteria 2000 (Lucena et al., 2008). The discussion also shows signs that the field favours international accreditation as the engineering role required more global working (Patil, Nair, & Codner, 2008).

Outcome-based curriculum – based on competencies defined by accreditation -is another specific logic that seems to be supported by the field as engineering education. It is seen to be constantly trying to conform to industry demands in exchange for employability of their students by the global market as well as their keenness to establish a relationship with industry partners for research funding. Collaboration of important stakeholders such as industry, academia, and professional bodies seem to be important in acquiring competencies capital. In a smaller scale learner centred methods and programs such as those using problem based learning and work integrated learning (Beanland & Hadgraft, 2013; Cook, Mann, & Daniel, 2017) and other methods of teaching and learning are beginning to emerge as rules reliant on collaboration.
Conclusion

This paper gives evidence that engineering education is a field with specific capital related to industry practice, competencies capital, and highlights part of the specific logic of the field as drawn from the transformation phenomena. We argue that by viewing engineering education as a field, one is able to provide a more critical analysis of issues of practice in engineering education because of the ability to understand different agents’ viewpoints because their position is determined by capital and conforming to the specific logic. The available literature, although reflecting the transformation occurrences in a wide part of the world and oftentimes assuming that it has represented transformation of the field of engineering education, only represents what is happening in some countries - hence gives the Global North perspective of that field. There are parts of the world that have yet to adopt such procedures like program accreditation or outcome based education (Matemba & Lloyd, 2017), which seem to be the implicit rules of the engineering education field. When considering the capital valued by the field (competencies), it is obvious that the global and technological trends have made it crucial for engineering education in any country to constantly strive to acquire that capital to ensure competitiveness in the global job market. What are the implications of having a set of rules for obtaining the field’s capital that is not conversant to the other part of the world such as most countries in Africa, the area that the wider doctoral research is focused on? In terms of field this may implicate issues with regards to the specific logic, which are important in participating in engineering education field. Hence theoretically we will be able to clearly expose some inequalities in acquiring capital in the field – the dominant agent and the dominated parties.

The significance of this paper is its use of the engineering education trajectory to construct engineering education as a Bourdieusian field. We thus provide an opportunity or possibility for researchers to engage in reflection, discussion and research of engineering education from a social theoretical viewpoint. Given engineering education is influenced by national and global socio-economic and political contexts, the application of a Bourdieu’s social ‘theory of practice’ to define engineering education as an explicit field is of significance to researchers and educators.

References


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Web tools for curriculum co-design: An indicator of engineering student graduate attributes

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Abstract: In response to skills required by employers, universities have introduced graduate attributes (GAs) which students should develop during the course of their degrees. This paper describes an innovative approach where web tools are used by fourth year engineering students at a University of Technology (UoT) to create curriculum material for their courses and simultaneously assist them with the development of GAs. This mixed methods research demonstrated that, in addition to improving their discipline specific knowledge, a web tool project contributes to the development and expression of a number of graduate attributes. The results imply that other engineering courses should consider the adoption of a teaching strategy where web tools are used by students to develop curriculum content and thereby assist with the development of GAs.

1 Introduction
Increasing emphasis has been placed on South African universities to identify appropriate graduate attributes (GAs) (Winberg, Staak, Bester, Scholtz, Sabata, Monnapula-Mapasela, Sebolao, Ronald, Makua, Snyman and Machika 2017). Moreover, in recent years, developments in higher education such as the Fees Must Fall (#FMF) movement highlighted that transformation is required in two key areas namely the use of technology and curriculum design (Langa 2016). Against this backdrop, heightened awareness has arisen of changes required in teaching strategies in engineering education, at a University of Technology (UoT) in the Western Cape.

This paper describes the pedagogical context, methodology and the results of an intervention by two lecturers in different engineering departments at the UoT. The study set out to establish if the use of open access web tools (screencasting and wikis) to develop course material can simultaneously assist students with the development of GAs. Ultimately, findings suggest that the use of web tools by students to generate curriculum content is an appropriate and effective method to achieve institutional GAs. In addition to the acquisition of domain specific knowledge, students reported developing soft skills that are required by employers but are not specifically taught at universities.

2 Theoretical Framework
The foregoing commentary draws attention to the value of student generated content (SGC) developed with web tools, which leads to the realization of graduate attributes. Thus, a discussion on the theoretical concepts that are regarded as influential, as well as important contextual variables to this study, follows below. These concepts are GAs, Web tools, SGC and Active Learning.

2.1 Graduate Attributes
A decade ago Willey and Gardner (2008) reported a competency gap between the skills required by employers and those developed by students during their courses at universities.
With reference to this, Frawley, Dyson, Tyler and Wakefield (2016) refer to GAs as soft skills that students need once they finish their university studies, in addition to the domain specific knowledge required by their discipline. The authors argue that GAs can be developed through a web tool assignment whereby students “need to explain key concepts to peers”. They claim that such an assignment contributes to the development and expression of a number of GAs which include a student’s ability to communicate ideas, skills in multimedia, creativity, teamwork and self-directed learning.

According to Snowball and McKenna (2017), GAs ultimately make students part of the community of knowledge creators and members of a community of practice, rather than outsiders who passively receive knowledge, which is controlled and mediated by educators. The institutional GAs at the UoT where this research took place include ‘Technological Capability and Foresight’, ‘Resilience and Problem Solving Capability’, ‘Relational Capability’ and ‘Ethical Capability’. These are briefly outlined in the paragraphs that follow.

The UoT describes a graduate with technological capability and foresight as a person that recognises that society, technology and science are intertwined. Changes in society are therefore influenced by technology and science. Science and technology should be used for the overall benefit of society. A graduate who possesses resilience and problem solving capability recognises the complexity of problem solving in society (including technological problem-solving) and will be able to engage confidently with such complexity. Graduates are able to recognise that there are no simple solutions to problems in society and that they will need to act with resilience to succeed within entrepreneurial, innovation and investigative/research activities.

Relational capability refers the attribute that a graduate possesses which equips him/her to enter into professional relationships in order to obtain access to resources and skills, in particular those which are complementary to the professional activity. Finally, ethical capability refers to a graduate being able to stand in the shoes of others in order to understand their needs, values and cultures so that what is being worked on can have optimal effects and/or the best chances of success. Graduates should be able to act with understanding of others different from themselves, at both the interpersonal and inter-professional level endeavour to understand, learn with, and be able to engage with others for the best possible solutions to work and societal problems.

**2.2 Web tools**

Web 2.0 is a term that describes the evolving trends in the use of World Wide Web technology and its aim is to improve information sharing, collaboration and creativity through the web (Jadhav 2019). Associated with this, Warren (2019) defines a web-based tool (web tool) as an application or program which is software that runs on a web browser. In the context of this study, the wiki feature of a learner management system (LMS) and screencasting (screencast-o-matic) are regarded as web tools. The only user requirements to operate a web tool are the user needs an internet browser to be installed on the user’s device and the user needs to have an internet connection. The software that enables the web tool is installed and executed on a remote server, which is accessed via the web browser. Specialised software provides desktop-style application functionality through the user’s web browser frontend. A primary benefit of browser-based web tools is it is not required of the user to purchase special software as in the case of locally installed desktop applications. A further advantage of web tools is the remote hosting aspect. Implications of remote hosting are less storage space used on the user’s computer and the web tool can be accessed from anywhere in the world.

Coulson and Frawley (2017) argue that Web 2.0 tools allow students a voice in online spaces and therefore it has gained prominence in higher education. They cite discussion boards, which are now a standard feature in most major Learning Management Systems (LMS) at universities and promote social learning via collaboration, as an example. In addition, they propose that Web 2.0 has given rise to user-generated content and
participatory culture. This foregrounds the important role of web tools in higher education. Aligned with this, Cochrane (2013) proposed that curriculum integration of web tools in higher education is best achieved by moving away from a focus on the media themselves, towards designing authentic tasks and projects that emphasise collaboration and student-generated contexts. This study is an endeavour to do this.

2.3 Student generated content
Snowball and McKenna (2017) argue that the advent of Web 2.0 has greatly increased the potential production and use of student-generated content (SGC), such as wikis, blogs and podcasts, in higher education. They assert that SGC is not only associated with higher order learning outcomes and greater student engagement, but it also allows educators to bring student experiences and voices into the centre of the community of practice. Essentially this acknowledges the importance of students’ prior experiences in knowledge production.

This is consistent with the views of Coulsen and Frawley (2017) who advocate that when students generate multimedia, it places the student at the centre of their own learning. Thus, SGC is a move away from passive instructional methods. Importantly, students who produce or co-author learning material gain benefits such as technology skills, creativity, the ability to communicate knowledge and work collaboratively. Furthermore, the production of some types of learning materials, for example screencasts, can be very motivating to make in cultures celebrating multilingualism. This is significant in the context of this study which takes place in the Western Cape in South Africa. According to Western Cape Government (2019), the Western Cape has three official languages, namely English, Afrikaans and isiXhosa.

Moreover, Frawley et al. (2016) claim that when students become producers of learning material it helps them to become autonomous through repetitive production of learning materials, facilitated by varying rates of learning in collaborative environments which enables adaptive learning. Thus learner centred education aids in the development of graduate attributes in collaborative active learning environments.

2.4 Active Learning
Bransford, Brown and Cocking (1999) define ‘active learning’ as a classroom approach which acknowledges that learners are active in the learning process by building knowledge and understanding in response to learning opportunities provided by their teacher. They assert that active learning is underpinned by constructivist theory, which emphasises the formation of a new or enhanced understanding of concepts to existing knowledge and experiences from an encounter with new ideas and experiences. Bransford, Brown and Cocking (1999) and Brame (2016) agree that another term associated with active learning is project based learning (PBL), which they characterize as learning that happens through social interaction with a teacher or other students. Active learning implies that students are engaged in their own learning and the students’ efforts actively construct their knowledge.

In this regard, a web tool project such as the one designed by this study is believed to be capable of facilitating active learning or PBL.

Gee (2010) is of the opinion that within PBL, teachers can scaffold tasks, provide guidance and support that challenges the learner based on their current ability. In addition, the teacher also provides rich feedback through the medium of assessment, which drives the student learning experience toward deeper levels of understanding. Thus, in an environment where knowledge is situated in an activity bound to social, cultural and physical contexts, individuals learn through experiences. Learners are influenced by mediators (teachers) during PBL experiences, as well as by tools, technologies and languages used by the group. Within this context, nuanced meanings are given to the aforementioned by the collective group involved in the project. In this regard, aligned to the view of Vygotsky (1978), learners
are seen to take responsibility for their learning, teachers become enablers and activators of learning.

Therefore, on the foundation of the theoretical concepts presented in the preceding sections, this study is essentially an undertaking to determine if engineering students are able to use web tool to generate curriculum content during an active learning process, while simultaneously developing institutional GAs.

3 Methodological approach

This research took place from July 2018 until February 2019 in two different departments in the Faculty of Engineering at the UoT. Each of the two lecturers presented their respective final year BTech classes with a semester project which entailed the production of course material facilitated by a web tool. In August 2018, Lecturer One requested her students to produce a group wiki on a prescribed topic that had already been taught in class. Students were provided with a project brief, instructional wiki videos and a sample wiki. A rubric was provided to assess the content of the wiki report, technical functionality, individual and group contribution. The students were verbally informed that their wikis had to be of good enough quality for other students to use as an educational resource. They were also informed that their permission would be requested should their wiki be selected for re-use to teach other students. The project ran for five weeks and entailed peer-to-peer and lecturer to student feedback. Wikis closed in mid-October 2018. This semester project constituted 15% of their final year mark.

Simultaneously, Lecturer Two asked her students to create two 15 minute long screencasts on a topic that had already been covered in class. Students worked in groups and the two screencasts needed to be in two different local languages (either English and isiXhosa or English and Afrikaans). Students were given the rubric that would be used to assess the English screencast. The students were informed that the screencasts needed to be of good enough quality for other students to use as an open educational resource. Therefore, students were requested to grant permission to re-use their screencasts to teach other students. Groups submitted a draft English screencast, on which Lecturer Two gave them feedback. The final English screencast was marked by the lecturer. The translation of the other language screencast was peer-marked by other groups of students (only translation, not content) in a half blind peer review process. Screencasts were completed and submitted in October 2018. This semester project constituted 15% of their final year mark.

Following the submission and assessment of student projects, a mixed method approach was adopted to collect data from students. Data collection commenced in November 2018 with an online survey (n=57) which consisted of 27 likert scale questions and four open ended survey questions to obtain a richer and deep understanding of the students’ perceptions of their experience. The survey design enabled the construction of four latent variables on which correlation analysis was performed. Alpha Cronbach’s coefficient was used to ensure internal validity of the likert scale data. Thereafter, survey data was analysed using SPSS and was examined to determine the factors that influenced GAs during the process of using web tools to generate curriculum content. The four open ended survey questions were examined for recurring themes.

The findings of quantitative data analysis provided the basis for the development of the qualitative data collection instrument. The qualitative data collection instrument was designed to focus on four areas of interest namely, 1) the role of the web tools and GAs; 2) SGC and GAs; 3) the factors that influenced the process and 4) active learning. The focus areas were derived from the conceptual framework of the study. Since institutional GAs constituted a central concept of this study, a pre-interview briefing session was planned where GAs were defined and explained to the focus groups.

Two focus group interviews were conducted in February 2019 (n=3 and n=6). Interviews were conducted by an interviewer who was not the lecturer of the students being interviewed.
to eliminate bias and ensure the validity and reliability of research data. Interviews were transcribed, coded and thematically analysed. The codes and code families that were selected for thematic analysis were derived from the objectives of this study. Ethical clearance for this study was granted through institutional channels.

4 Results and discussion

4.1 Quantitative results

The quantitative results of this study indicate a correlation between ‘deeper learning’, ‘technical competence’, ‘responsibility’ and ‘collaboration’ for the students of both lecturers when web tools are used. Furthermore, alignment was noted between the aforementioned factors and competencies with the institutional GAs in the case of both lecturers. This study deduced that the aforementioned factors play a role during “the process” of using web tools to create student generated content. It is noteworthy that the findings of the quantitative data analysis highlighted that only the students that took part in the screencast project recognised the value of their contributions during curriculum co-design. The wiki project participants did not recognise the value of their contributions, as this outcome was not explicit in their instructional material but rather a verbal instruction.

4.2 Qualitative results

The qualitative results of this study are presented in order of the four concepts of the theoretical framework: Web tools and GAs, Student generated content (SGC) and GAs, Factors which play a role during the use of web tools and Active Learning and GAs.

4.2.1 Web tools and GAs

Consistent with the findings of Moalosi, Oladiran, and Uziak, 2012, our study found that the use of a web tool for the semester project assisted students in the realization of institutional GAs. With reference to technological capability, the students generally concurred that the use of web tools to complete their semester assignment developed technological capability and foresight. Excerpts taken from screencast-producing students in support of this are “the process made me more tech savy” and “It was (more), a kind of something that unlocks my potential ...that pushed me and stretched my mental capacity and capabilities”. Furthermore, students who produced a wiki said “Once I watched the instructional material, the wiki became easy to do” and “the wiki made the concept of what we had to do quite simple”.

In terms of relational capability, this study sought guidance from Coulsen and Fawley (2017) who argue that students who completed a web tool assessment task developed the ability to professionally communicate, collaborate and work in teams, in addition to key disciplinary learning, and despite many of them not having prior experience of this kind of assessment. They emphasized that participation in a web tool activity develops communication skills and improves teamwork when it is undertaken as a group exercise. This is consistent with reflections one student who stated “...(web tools) helped us to see the value of co-existence and interdependence because not all of our strengths are the same”. It is also noteworthy that in addition to this, a student mentioned that her experience was ‘fun’. She offered “It was quite interesting to hear and embrace (what) the other group members brought. The fun that was in that.... You had to trust your group mates”.

Disparity was noted between the responses of student participants’ views on the use of the web tool and the development of ethical capability. The UoT states that a graduate who possesses ethical capability is “able to stand in the shoes of others in order to understand their needs, values and cultures so that what is being worked on can have optimal effects and/or the best chances of success”. In consideration of this, it is worth noting that one student highlighted that it was significant to her that the final product of the web tool activity that she partook in (the production of a screencast) was intended to be used by other students and the general public who would are not able to afford to go to university. In contrast however, a wiki-producing student indicated that ‘if I had known that I was
contributing then the wiki experience might have been more fun and I would have made a better effort.’ Upon reflection of this it was realised that the students were given a verbal instruction and not a written instruction. This research deduces that a verbal instruction is not enough.

With reference to the resilience and problem solving capability GA, it was noted that all the students who were interviewed in both focus group interviews agreed that initially, the web tool activity was an incredibly challenging and complex task for them. All the students however conceded that the software was relatively self-taught and easy to use. Thus, after some practice they were all sufficiently skilled to use it proficiently. It is worth noting that one student said that “this experience reflects what happens in the real world”. A student who produced a screencast explained “...we struggled. And we ended up thinking how can we achieve this thing… We knew that we don’t understand but we did not want to get to that level of saying guys let’s get someone else who is going to do this for us. We wanted to do things on our own to see how comfortable we are”. Another different student who produced a wiki shared that although he encountered technical difficulties with the wiki task, the nature of the web tool challenges compelled him to seek innovative solutions to overcome his challenges. For example, he said “where we could not do things in the wiki we did it in MS Word and pasted it over”. These findings are aligned with the view of Coulsen and Fawley (2017) who reported that the attitudes of students varied in accordance with student self-efficacy and confidence. Furthermore, the self-directed nature of the web tool task appears to be both an opportunity and a challenge for students.

4.2.2 Student generated content and GAs

The intention of web tool project for both wiki and screencast producing students was that the outcome of their projects, namely wikis and screencasts, could be used by other students. The final users of the educational resources (wikis and screencast) would be students who did not participate in the project. This study highlighted the importance of explicit communication when student generated content is produced. A significant finding of this study is that some students reported that they were not aware and therefore this affected their contribution. It is worth noting however that in the same focus group another student reported also not being aware but that it did not make a difference to the amount of effort he put in.

Importantly however, students who produced screencast indicated that they were all aware of the fact that they were developing content to be used by others and this positively influenced their contributions. One student said “This will be seen by people so you need to be sure of what you know and what you are talking about so that whoever is listening to it can understand it”. Moreover, another student said “With us making those screencasts I was just thinking a person growing up in a rural environment, if they can to an internet cafe and have access to our screencasts they won’t actually need to go to university to be taught what we are being taught”. She added “They’d be able to sit in front of a computer as long as there is WiFi and tap into this sea of knowledge”. This study therefore deduced that the activity of producing student generated content facilitates the development of the ethical capability.

In terms of relational capability, a significant finding of this study was that the group work aspect of the web tool project enabled relational capability. With regard to developing curriculum content one student stated “When three ideas are jointly put in the same (idea) then something more valuable comes. It taught me to identify when you are unable to do something and [sic] somebody can be able to do it better than you”. This view was supported by different student who stated “For me it was something that helped to recognise someone’s strengths and someone’s weaknesses because we come from different cultures and have different values... so we all learn from the other person. So we understand and we try to make you understand because we also know that at the same time you are gonna help us”. She added “We learnt a lot because we come from different cultures and we learnt to respect one another’s view or opinion, so that made me realise the value of respect”. Furthermore,
with reference to relational capability in terms of producing content that is intended to be viewed by other students, a student said “You need to be professional because you are talking to people who you do not know, but at the same time you need to be understandable to everyone”. This study therefore gleams that when a web tool is used by students to co-create curriculum content, it facilitates relational capability.

Stipek (1996) suggests that student success may be defined in terms of mastery and personal improvement rather than in terms of performance relative to others. With reference to the UoT’s resilience and problem solving GA, in this study we found that students responded well to generating curriculum content when using a web tool, describing it as an ‘opportunity to impress as no one had used it before’ and ‘this experience motivated us to go the extra mile’. These student perceptions underpin their enthusiasm in the face of completing a complex problem and this demonstrates their resilience capability in the completion of the academic project. Further excerpts that illustrate this are “The first screencast was a nightmare. We probably took a week to record like 15 minutes, which was the best thing ever, because when we did the next one we spend like less than an hour recording the second one” and “Sometimes you have to do it over and over again to do it right. That’s resilience to me. But at the end, we finally got the result and then at the end it kind of gives you a better sense of worth, that you are able to do something that is new”. During the development of curriculum content, students are required to pose questions, evaluate evidence, connecting evidence to pre-existing theoretical knowledge, drawing conclusions, and reflect upon their findings. These are typical project activities which result in the attainment of creative and critical thinking skills (Maolosi, 2012). Moreover, from this study, we were able to deduce that the project experience is elevated by the use of a web tool and this is evidenced by statements such as “The web tool motivated us to go the extra mile. No one else had used it before and we wanted to impress”. An inadvertent consequence of this is students’ technological competence and foresight and resilience and problem solving GA is then simultaneously easily fulfilled.

4.2.3 Factors that play a role during the process of using web tools

At the commencement of the co-design process students seemed to consider the curriculum as something that is primarily related to what had to be learnt and not something that had much to do with their learning processes. However, through their subsequent project engagement with instructional material, their web tool and with each other, a shift toward understanding the outcome of student contribution took place. It was noted that a transformation occurred during the aforementioned process, of applying their individual attributes toward a singular goal rather than individual goals. In this regard, the analysis of the quantitative data of this study prompted this study to explore three main factors that play a role in the process. These factors are responsibility, collaboration and technical competency.

Consistent with the findings of Garcia, Noguera and Cortada-Pujol (2018), student respondents in this study generally articulated positive views on the use of web tools in the academic project. Some students concurred that a significant strength was the fact that it gave them more autonomy and responsibility in the process evidenced the statement of one student who said “I did my job and they did theirs”. This study considers this an indication that the project activity facilitated both collaboration and responsibility. Furthermore, this study noted that students initially regarded self-sufficiency to be a strength, however this also led them to feel insecure and in greater need of educational guidance and peer to peer collaboration to ensure they did not get lost during the process.

The view of Gee (2010) supports this, as he is of the opinion that within PBL, teachers and other mediators (peers) can provide guidance and support in the way of instructional material and rich feedback that informs their experience timeously. Peers can confirm or redirect the activity in terms of the collective understanding. This was articulated by one student who said
“they did not grasp the concept at first but the dummy wiki and group interaction helped with understanding and recognising that the concept was quite simple”.

With reference to technical competency and complexity, Coulsen and Fawley (2017) found that students were able to navigate between new tools and methods to achieve a complex task. This is consistent with the finding of this study since students reported that they easily navigated technical competency as they wanted to do well. Excerpts such as “the planning part taught me that you need to have your ducks in a row first before you can produce this awesome end product” and “the project taught me that you need to roll with it, otherwise you’ll be left behind. It was really cool that we got to do this project in in another language; it was challenging but also awesome because we reached a bigger audience via this technology and that was awesome” serves as evidence of this.

4.2.4 Active learning and GAs

On the basis of the definition for Active Learning (also referred to as PBL) by Brame (2017), being “instructional activities involving students in doing things and thinking about what they are doing”, this study involved a PBL approach. Students confirmed this with statements such as “It was difficult but it’s a nice tool (web tool) to use when you get used to it”, “It’s much better (web tool) because of the type of work. Though you have to organise some pieces but in the end this one is kind of challenging and more fun than paperwork” and “To me it’s more than being a better way… if you looking at something you not gonna get bored. You gonna say what’s coming more, what’s coming, what’s coming”.

Previous studies (Snowball and McKenna 2017, Coulsen and Frawley 2017, Frawley et al. 2016) suggest that PBL is an appropriate teaching strategy to assist students with the realization of GAs. The integration of specific skills (GAs) in university curriculums demands a new approach to the practice of learning, teaching and assessment. In a study undertaken by Maolosi et al. (2012), student perceptions indicated that GAs such as creative thinking skills, accountability and ethical standards, and critical thinking skills were the competencies most attained in a project design environment. Similar student perceptions were found in our study which was also within a project design environment. Students felt that the GAs of technical capability and relational ability were easily attained. Perceptions such as “once we realized it was easy it was not as challenging” and “the wiki motivated us to go the extra mile. No one else had used it before and we wanted to impress” attests to this.

It is noteworthy however that some students do not realise that they had developed GAs. An example of this is illustrated in one student’s reflections on relational capability “It created tension if you just did your own thing; so it actually was necessary to work together as a team. It was important” and resilience and problem solving capability “if there was something we could not do in the wiki , we did it in MS Word and then pasted it in the wiki”. Some students verbalised that they had not experienced ethical capability; however the comments they made in the focus group interview suggests that they did, such as “the wiki helps to see who is doing what so we do not repeat work and we do not just change without permission”.

Considering that the students’ conception of learning was quite traditional (non-web based) and that they had relatively little experience of active and student-centred learning methods, it is of particular interest to this study that they valued the web tool approach and adapted their competencies so easily. Significantly however, this study has shown that a transformation took place in the students who took part in this study in terms of them developing all the UoT’s institutional GAs.

Recommendations

This study explored whether students are able to contribute to the design of engineering courses while concurrently undergoing personal growth in their critical thinking, problem solving, communication skills and acting in the best interest of themselves and their peers. The quantitative and qualitative findings of this research suggest that this realization occurred in the engineering students where this study took place.
The research of Moalosi, Oladiran, and Uziak (2012) proposed that web tools are an appropriate and effective tool to use to develop GAs in students. The findings of this study are consistent with their proposal, since analysis of qualitative data in this study indicates that the students who took part developed all four of the UoT GAs. In some instances, the students did not realise that they had developed GAs since they stated that they did not, however their responses imply that this was in fact not the case. In addition, against the backdrop of Snowball and McKenna (2017) and Coulsen and Fawley (2017)’s argument that educators are able to create a PBL environment in which students can create content which brings the student experiences and voices into the centre of the community of practice, this study confirms that this practice develops GAs. Essentially, it acknowledges the importance of students’ prior experiences in knowledge production. A recommendation of this study is therefore that engineering students use of web tools, to generate curriculum content in their courses.

Significantly, this study also deduced that the use of web tools to generate curriculum content constitutes a form of active learning. Active learning in a PBL environment takes place when students make connections between new information and their current cognitive models, thereby extending their own understanding of a concept (Brame 2017). Therefore a further recommendation of this study is that engineering courses consider promoting PBL as a strategy to ultimately help students develop GAs, since this study demonstrate the association between PBL and GAs.

Conclusion

Engineering graduates require competencies in addition to discipline specific knowledge that is important for professional engineering practice. Therefore, appropriate teaching and learning strategies must be employed at universities to ensure that each engineering student is able to develop the GAs that they require by the completion of their course. This study was an undertaking which explored the value of web tools in a PBL environment in the aforementioned context. Web tools served as a vehicle which enabled students to developed course material (referred to as SGC) and concurrently promoted the development of GAs in the students.

The result of this research is that, in general the students enjoyed a challenging yet positive experience. This study found that the design of PBL environment is however essentially important and critical to the success of the development of GAs in engineering students. Students need to be given clear instructions with associated expectations, clear assessment criteria, good quality support instructional material and formative feedback opportunities. This study therefore recommends that other engineering courses duly consider the incorporation of a teaching strategy where web tools are used by students to develop curriculum content, while simultaneously developing GAs.

References


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Perceptions of Interdisciplinary Learning: a qualitative approach

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Abstract: Despite the fact that interdisciplinarity is on top of the agenda at many higher education institutions, there are few practical guidelines on which to build interdisciplinary engineering curricula. This study focused on how interdisciplinarity is perceived at TU Delft, which interdisciplinary skills are assessed in these programmes, how these are assessed and how they relate to the interdisciplinary problem being addressed. Results indicate that the perception of interdisciplinarity varies thereby influencing programme design. Communication and collaboration skills are important interdisciplinary skills. Assessment of these skills seem in its infancy. We may conclude that interdisciplinarity seems only occasionally to be a systemic endeavour due to different interpretations of interdisciplinary education itself and subsequently the knowledge of how to design interdisciplinary education.

Introduction

The Royal Academy of Engineering in the UK identified in 2006 the new engineer as integrator: a graduate who can operate and manage across boundaries and who can be very technical or organisational in a complex environment (Schoenmaker, Verlaan & Hertogh, 2015). Despite the fact that interdisciplinarity has been on the top of the agenda at many higher education (Holzer et al., 2016), there are few practical guidelines on which to build interdisciplinary engineering curricula. In the TU Delft Educational Vision, interdisciplinarity is one of the important learning outcomes for future engineers. This paper, therefore, aims to gather insight into the design of interdisciplinary courses at Delft University of Technology, The Netherlands. Six interdisciplinary minor and one master programmes were evaluated by means of semi-structured interviews and document study and analysed in a qualitative way.

Intrinsic to scientific research is the development of an overall education in which the individual should do scientific research to discover new scientific territory (Scott, 2016). The Humboldtian academic model in which independent research, study and academic freedom was intended, has been adapted to modern day higher education via the Bologna agreement. These principles are still at the very heart of academia and are revived in different formats of teaching for 21st century.

One of these formats is interdisciplinary teaching/learning. Interdisciplinary learning is currently not systemically embedded into our university. As interdisciplinary learning offers a close relationship between research and teaching, it creates autonomy for students to pursue their own research questions. Many researchers Repko (2008), Thompson Klein et al., (2014) and De Greef, Post, Vink & Wenting (2017) tried to capture the complexity of what
interdisciplinary teaching/learning entails, the opportunities for innovation and how to design it for engineering students. Yet various researchers point out that from different educational research paradigms, the best interdisciplinary teaching and learning design has not yet been extensively addressed (Boon & Van Baalen, 2019), Spelt et al., (2017) and Macleod et al., (2016)).

Earlier research (Klaassen, 2018), evaluating two MSc curricula at TU Delft, shows that the design of interdisciplinary learning is based on the chosen problem and the research paradigm chosen to solve this problem. This problem is, thus, central to the learning outcomes, the level of integration and the constructive alignment of the programmes. The perception of teaching staff of interdisciplinarity thus indicates to what extent this idea is of relevance to the design of interdisciplinary education at our university.

The research question in this study is: “How is interdisciplinary education currently structured in engineering education in the perception of programme coordinator/lecturers and which key parameters can we identify to support future curriculum design?”

**Theoretical framework**

Interdisciplinary research can be defined as an integrated approach of different disciplinary methods, knowledge, skills, theories, and perspectives, to realize innovative solutions and knowledge advancement in uncharted problem areas, by a team or individual scientists (Castán Broto, Gislason & Ehlers, 2009, Lam, Walker & Hills, 2014, Menken & Keestra, 2016, Boix Mansilla & Dawes Duraising, 2007). In interdisciplinary education students acquire the skills to conduct interdisciplinary research in practice or in science. These skills are framed as interdisciplinary thinking. What interdisciplinary thinking is, however, is widely debated. Some researchers talk about “knowledge of” in depth knowledge of another field and “about-knowledge” a rudimentary form of knowledge about another field (Priaulx & Weinel, 2018) or they talk about skills (De Greef et al., 2017). Additionally, it matters whether interdisciplinarity is narrowly defined (within one domain) or between broadly different domains (Gantogtokh & Quinlan, 2017). Spelt (2017), eg. states interdisciplinary thinking is the capacity of students to integrate interdisciplinary knowledges from broadly different disciplines and more narrowly related disciplines. Boon et al., (2019), frames it as metacognitive awareness and application of disciplinary paradigms, theories and methods. Repko’s (2008) states perspective taking and structural problems solving inquiry by understanding interdisciplinary problems and integration of knowledge is needed. Klaassen (2018) shows students are taught different skills dependent on the scientific disciplinary approach, i.e. design abductive or inductive/deductive research methodologies, resulting in different levels of integration.

Neither the knowledge level nor the skills are precisely defined. The assessment thereof is a challenge. There is a lack of methods for judging interdisciplinary education and its direct impacts on student learning, especially at the undergraduate level (Repko, 2008). In this study we have looked at what we can learn from emerging practices at our institution. We have used an analysis model which has been validated in 3TU context and particularly looks at the course design parts vision and education (Figure 1). The framework was established on the basis of a literature review of 93 Scopus articles on interdisciplinary learning in engineering education and on the basis of data collection of six case studies across the three technical universities in the Netherlands. The framework primarily focuses on the constructive alignment of the courses; i.e. conceptualizes this alignment between the educational vision, operationalization into pedagogical approaches and facilitation by support structures and together are indicators for the analyses of educational design (Klaassen, 2018). In this paper we focused on the vision and educational part of the framework.
Figure 1: Framework for Interdisciplinary Engineering Education (4TU Centre for Engineering Education).

Methods
In this study we have chosen to use qualitative semi-structured interviews, to get a handle on a broad range of processes used and the perceived reasons for using a particular educational design format. The open topicalised questions allow for explorations of the insights and perceptions of the interviewees.

The sampling of the interviewees focused on programme responsible coordinators as they largely decide, with their staff, what a programme should look like, which values it comprises and how it ought to be assessed. To start, we have chosen programmes at our institution, which in the study guide have been announced as interdisciplinary. These turned out to be minor and some master programmes, by and large in the area of design engineering or sustainability in both of which interdisciplinary problem solving is important. This study is part of a larger study in which around 15 interviews will take place. At the time of writing seven interviews were conducted of which the results are reported here. The interview questions were in line with those used in the framework and 4TU Case studies (Van den Beemt, forthcoming, Boon et al., 2019, Klaassen, 2018). The 4 main interview questions discussed in this paper are (1) What is your vision on how to realise interdisciplinary education? (2) Which type of problems are addressed in the programme? (3) Which skills and knowledge need to be acquired in the interdisciplinary programme? (4) Which methods of assessment are used? These questions are a selection of 10 questions used in the interview and corroborating the indicators.

The interviews were transcribed and analysed in Dedoose (a qualitative research software package). The analysis involved coding of the interviews on 11 indicators, together covering the fore mentioned framework by three coders. Due to limited space, in this article results are presented of 4 indicators only, which are Vision, Interdisciplinary problems defined, Skills and knowledge of students and Assessment, together covering the Vision and Education part of the Framework. These 4 codes are chosen as they address the constructive alignment of curriculum design. The codes are equally derived from earlier studies by Van den Beemt et al. (forthcoming), MacLeod (2017), Boon et al., (2019) and Klaassen (2018).

Inter reliability is used to sustain the consistency in coding and come up with more reliable results then random interpretation (Keyton et al., 2004). In Table 1 the number of excerpts for each code is listed, the interrater reliability, Cohens Kappa (CK), between each pair of raters and an overall average kappa across the 3 raters. Although the interrater reliability is ideally calculated via a method which includes multiple raters, we were limited by the possibilities in the research software package. We therefore concluded CK between raters and overall across raters as the closest measure of reliability available. CK for each indicator was moderate to fair. The average CK was .67 moderate to fair (Sun, 2011).
Table 1: Number of excerpts for each indicator and interrater reliability (Cohens Kappa).

<table>
<thead>
<tr>
<th>Indicator</th>
<th># Excerpts</th>
<th>Rater 1-2 CK</th>
<th>Rater 1-3 CK</th>
<th>Rater 2-3 CK</th>
<th>Average CK</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vision</td>
<td>181</td>
<td>0.64</td>
<td>0.55</td>
<td>0.57</td>
<td>0.59</td>
</tr>
<tr>
<td>Interdisciplinary problems defined</td>
<td>50</td>
<td>0.61</td>
<td>0.51</td>
<td>0.75</td>
<td>0.62</td>
</tr>
<tr>
<td>Skills &amp; Knowledge students</td>
<td>109</td>
<td>0.70</td>
<td>0.56</td>
<td>0.63</td>
<td>0.63</td>
</tr>
<tr>
<td>Assessment</td>
<td>73</td>
<td>0.83</td>
<td>0.83</td>
<td>0.83</td>
<td>0.83</td>
</tr>
<tr>
<td>Total CK</td>
<td></td>
<td>0.70</td>
<td>0.61</td>
<td>0.7</td>
<td>0.67</td>
</tr>
</tbody>
</table>

For additional information on specifically the learning objectives and assessment methods, most interviewees referred to their study brochures, the online learning environment, and study guide information. This information has been taken into account in the interpretation of the interview results. Extensive discussions of triangulation and literature discussion go beyond the space available in this paper. The coded interviews excerpts agreed upon in the coding process have been clustered and summarised with the literature and other data-source in mind.

The results section will discuss the combined interview data on vision and education in a sequential order. First visions of curriculum design, subsequently the interdisciplinary problems defined, the skills and knowledge and assessment in the last paragraph. The paper will finish with a discussion on the findings.

Results

In the minors/masters selected in this study the main learning outcome focused on sustainability (four interviews) or design engineering (three interviews) and inherently are expected to have an interdisciplinary educational design.

The Framework: Vision

In the theoretical framework the research team has defined interdisciplinarity as: a team or an individual expert who integrates different disciplinary methods, knowledge, skills, theories, and perspectives, to realise innovative solutions and knowledge advancement. When talking to the interviewee’s it surfaced in the conversations that each of them is struggling with what interdisciplinarity is and what it should or could be and what interdisciplinary design of education is. Differences in visions were established between interpretations of broad and narrow interdisciplinarity, inter and intra disciplinarity, differentiation between bachelor, minor and master foci in interdisciplinarity and possibly the irrelevance of talking about interdisciplinarity per se.

Broad (unrelated) and narrow (interrelated) disciplinarity is traditionally considered as going beyond one’s own discipline to a large or limited extent (Gantogtokh & Quinlan, 2017). However, going beyond one’s own discipline depends on the point of reference. If we look from the outside, one of our interviewee said, “we are all engineers”. Interdisciplinary at that moment is going beyond the institutional boundaries. Two other quotes to illustrate this are:

“When we look inside our own institution, interdisciplinarity goes beyond the boundaries of the faculty or departmental education programmes offered, and does comprise engineering in all cases”.

The interviewee further observes; “Also depending on the topic, I may be closer to staff at other faculties dealing with the same topic from a different perspective than some of the staff in my own faculty”.

These viewpoints show the fluidity of the term interdisciplinary.

Inter and intra- disciplinarity provides a different view on the issue of definition. Intra is an approach where the problem is solved from one paradigmatic perspective, but the input is from multiple sources. It is particularly applicable to design and sometimes also categorized as transdisciplinary, where the solution asks for involvement of experts and laymen of
different disciplines, but tends to be solved from one paradigmatic disciplinary view. One of the interviewees formulated the inter and intra-disciplinarity and even extents this intra to anti-disciplinary, as follows:

“Interdisciplinarity is a difficult construct, as a designer, I think that most designers are not aware of the fact that they work interdisciplinary, it is however, the usual way of working to dive into different disciplines to make a product. Each design is operated in a different context, in which you need different sorts of knowledge and communications with different experts. In my opinion you are taught here to be flexible and talk/deal with different disciplines. Therefore I think we should not try to give everything a name when we are talking about content. I am anti disciplinary. After all disciplines are men made barriers or obstacles given a name”.

Bachelor, Minor, Master level courses can all be interdisciplinary in their design, yet have a completely different purpose. In the minor no prior knowledge is presumed, nor any overlap with course in other programmes. The idea is about building common ground, to broaden the perspective and acquire a different way of thinking. “When they (=students) manage to come to a joint conclusion or decision it is already a wonderful result”. According to the interviewees it is more about providing “context”.

The focus in the bachelor is to give a broad idea of a specific topic within a discipline. On having a complete understanding of lots of different parts. Interdisciplinarity in bachelor courses might therefor necessarily focus on collaboration and teamwork and less on integrative solutions.

“Master level interdisciplinarity is a dynamic system, it represents a process which develops its own standards and quality norms and occasionally, develops into a new discipline. Within the dynamic system one finds all kinds of frameworks and methods, each with their pros and cons. The key is to each time consider, what is the context, what knowledge is available and which questions need to be answered to proceed in the research/project. Which discipline it belongs to is less relevant.”

Interdisciplinarity per se is not a goal in itself as most of the interviewees have made clear. They even warn not to construct interdisciplinary courses for the sake of the courses;

“Is it complex because it is interdisciplinary or is it interdisciplinary because it is complex”? The warning is elaborated upon; “To solve a complex problem one needs different types of expertise to come to an innovative solution which is relevant for society. Yet we should not pretend to solve everything by realising integration or interdisciplinarity, when there are essential differences between the disciplines”.

It is then stated a pragmatic way of working should result in reducing complexity. “In the end a theory or method whether regular, integrated or interdisciplinarity is about reducing complexity, tying the right knots, broadening perspectives and creating resilience”.

The Framework: Education

In this section we will describe the results of interview questions 2 and 3 of the interview protocol, about the definition of interdisciplinary problems, skills and knowledge needed and assessment methods used.

Interdisciplinary problems defined

In these interviews we have noticed the design is shaped by the problem definition in both areas of design and sustainability.

The problems are characterized by open problem definitions of real life, societal and complex problems. These problems are usually defined by the students themselves within certain boundaries. The solution space typically involves the consultation with multiple stakeholders. Last but not least the problem is ideally resolved by abductive design research, allowing
multiple problems with multiple solutions paths. Abductive design research would be more applicable to design and to a lesser extent to sustainability and engineering design.

The solutions space is broad - to very broad. The key to a “good” solution is a good problem statement, it should be i.e. controversial, complex, involving multiple stakeholders, inviting multiple perspectives, involving different scientific paradigms. The problem is solved by working from certain frameworks e.g. theory of systems, socio technical solutions space, etc.

A selection of various examples of problems defined by teaching staff and investigated by students within different cases are e.g.:

- Working on the green/blue structure of a deprived Neighbourhood in a big cities
- Fossil fuel is necessary for our energy transition
- A different solution for shoe laces, comfortable and supportive for everyone’s feet
- Monitoring human movement efficiently in particular situation.
- Guiding the blind (without dogs)
- Sustainable energy transition in harbour area
- Climate adaptation in the city
- Sustainable airport design

Students need to be able to work in an interdisciplinary way to come to a problem solution and they need to be able to frame their own problem definition. Obviously this needs to be learned gradually, by first providing a set of topics, gradually moving to more open and long term topics to be dealt with. According to several interviewees the innovation learning process is a precondition to acquire the capacity to actualize abductive design research and solve complex problems. The interviewees state the “innovation process” skills are only available in students with a design background and thus requires students in an interdisciplinary team to help solve these type of problems. Another perspective is that the technical, analytical power of the engineering students needs to be on board, otherwise solutions will be very superficial. Each interviewee had his/her own conviction as to what the different science fields bring to the table and the added value to the solution of the problem at hand in line with the epistemic differences in different scientific fields. Table 2 shows the contributions of different scientific fields to solution of the problem, in accordance with the interviewee’s visions on core skills in different disciplinary fields.

Table 2: Contribution of different science fields to problem solving according to the interviewees.

<table>
<thead>
<tr>
<th>Science field</th>
<th>Contribution to problem solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical</td>
<td>analytical &amp; practical results</td>
</tr>
<tr>
<td>Natural</td>
<td>scientific substantiations, modelling</td>
</tr>
<tr>
<td>Social</td>
<td>writing skills, philosophical reasoning (logic)</td>
</tr>
<tr>
<td>Design</td>
<td>problem definition, ambiguity, visual representation</td>
</tr>
</tbody>
</table>

Student’s skills and knowledge (SKA) needed for interdisciplinary ways of working and their assessment

During the interviews we came past many instances where the interviewees reflected on what types of students were in their minors/masters, how they enrolled students and what they might actually need as an entry level to successfully work on the learning outcomes. Observations are that the students are from a wide variety of backgrounds ranging from social, natural sciences to all of the engineering and design sciences, equally many students have a multicultural background. Sometimes entry level criteria are formulated. These criteria are however rather general, as it seems hard to estimate both what the entry level is of the students and what might be needed in their own disciplinary course to realise a “good” enough learning outcome. General entry level criteria, pertain to relevant background knowledge, mathematics, English writing, communication skills and collaboration skills.
Other observations pertained to the age of the students: younger students need more guidance and input when sharing knowledge.

The unbalanced level of prior knowledge within one course often leads to boredom for some students and to challenges for other students in the same course. Interdisciplinarity would definitely benefit from flexible learning paths as described by some interviewees.

The skills set acquired in the interdisciplinary programmes tended to be two-fold. Skills necessary for working interdisciplinary and skills necessary to deal with the content offered in the programme. The skills for working interdisciplinary were communication skills and managing the groups’ collaboration process in both the design and sustainability courses. Yet we find slight differences between the skills sets. An overview is given in Table 3.

Table 3: Student’s skills for working interdisciplinary in sustainability and design courses as derived from the interview excerpts (LO=learning objective).

<table>
<thead>
<tr>
<th>Sustainable: skills for working interdisciplinary</th>
<th>Design: skills for working interdisciplinary</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Communication skills</strong></td>
<td><strong>Communication skills</strong></td>
</tr>
<tr>
<td>LO: need to communicate ideas from different backgrounds to other teammates.</td>
<td>LO: academic argumentation to support their design choices/plan</td>
</tr>
<tr>
<td>LO: explaining own domain to others within other domains</td>
<td>LO: being able to work together with different disciplines</td>
</tr>
<tr>
<td>LO: teach them how to give feedback and how to work together</td>
<td>LO: reflection</td>
</tr>
<tr>
<td>LO: different jargons used in different disciplines should be discussed</td>
<td>LO: interpersonal capacities to lead others in your ideas</td>
</tr>
<tr>
<td><strong>Manage group collaboration</strong></td>
<td><strong>Manage group collaboration</strong></td>
</tr>
<tr>
<td>LO: integration of theories from different disciplines; but content level should be high level.</td>
<td>LO: how to work in interdisciplinary group</td>
</tr>
<tr>
<td>LO: need input from other disciplines to deliver the output</td>
<td>LO: soft skills working together</td>
</tr>
<tr>
<td>LO: working in a team and project approach, split in different working area’s and deliver product</td>
<td>LO: how they work together peer review</td>
</tr>
<tr>
<td>LO: understanding the disciplines, knowledge and skills to be used for a certain solution and coordinate this</td>
<td>LO: taste of interdisciplinarity</td>
</tr>
<tr>
<td>LO: students need to think about their own skill development to help them with more in-depth knowledge</td>
<td>LO: working together interdisciplinary by going out of one’s comfort zone (attitude)</td>
</tr>
</tbody>
</table>

When looking at communication skills (Table 3) deemed necessary for interdisciplinarity, there is more emphasis on explanation and understanding one another in the sustainable area, whereas in the design it seems to be more based on having the best argument for a particular concept. By following the theory of constructive alignment, we would argue that skills necessary for interdisciplinarity are also assessed. However, when we consider the assessment methods/criteria in design, there is no particular assessment method or criteria used to assess interdisciplinarity. In sustainability there is more emphasis on the relevance of each disciplinary contribution, which still is not really assessed (Table 4).

Table 4: Assessment methods and criteria in design and sustainability on interdisciplinary skills communication and managing group work, as derived from the interview excerpts.

<table>
<thead>
<tr>
<th>Design</th>
<th>Assessment methods</th>
<th>Assessment criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Communication</strong></td>
<td>Students need to talk to each other to integrate knowledge. This is not assessed</td>
<td>Solution not assessed on interdisciplinary aspects</td>
</tr>
<tr>
<td><strong>Managing group work</strong></td>
<td>Shared report based on student’s contribution Assignment in interdisciplinary groups</td>
<td>Teambuilding not assessed Maybe assess working together and what they have learned rather than a better solution? Teamwork could</td>
</tr>
</tbody>
</table>
be assessed if more structure to do this is provided.

<table>
<thead>
<tr>
<th>Sustainable Assessment methods</th>
<th>Sustainable Assessment criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication</td>
<td>It is assumed that all students have integrated the knowledge and learned from the project. This is not assessed</td>
</tr>
<tr>
<td></td>
<td>No interdisciplinary criteria Explain why all different disciplines are required, how they strengthen each other No integration rubric available</td>
</tr>
<tr>
<td>Managing group work</td>
<td>Group work assessments 2nd year: report</td>
</tr>
<tr>
<td></td>
<td>Process is assessed, not so much the disciplinary knowledge Peer review</td>
</tr>
</tbody>
</table>

The other part of interdisciplinary skills necessary is to deal with the content offered in the programme. In the sustainable area we find there is a lot of emphasis on using other (relevant) disciplines and the integration thereof (Table 4). This tends to be assessed through the process/ peer review methods, through group work and report writing. In the design area the focus is more on teamwork and skills to work effectively in teams, this may have a taste of interdisciplinarity, but is not focused on it. Even the teamwork, albeit very important, is not the focus of assessment. Results of content skills mentioned and assessment methods and criteria are presented in Table 5.

Table 5: Content (cognitive) skills mentioned in sustainability and design programmes and their assessment method and criteria, as derived from the interview excerpts

<table>
<thead>
<tr>
<th>Sustainable General skills/knowledge</th>
<th>Design General skills/knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO: able to reduce complexity</td>
<td>LO: modelling and calculations</td>
</tr>
<tr>
<td>LO: arranging input from other disciplines to deliver the output</td>
<td>LO: how well is the plan supported by scientific argument in favour of a decision?</td>
</tr>
<tr>
<td>LO: integration of theories from different disciplines; but content level should be high level</td>
<td>LO: learn a certain process approach</td>
</tr>
<tr>
<td>LO: using relevant information sources</td>
<td>LO: technical plan is sufficient</td>
</tr>
<tr>
<td>LO: work with different machines to be able to make concept scenario’s</td>
<td>LO: design skills</td>
</tr>
<tr>
<td>LO: computer programming</td>
<td>LO: materials knowledge, 3d-printing and other application techniques</td>
</tr>
<tr>
<td>LO: design (of sustainable plan) and application</td>
<td>LO: how to develop a problem solving strategy</td>
</tr>
<tr>
<td>LO: reporting and modelling skills</td>
<td></td>
</tr>
<tr>
<td>LO: research and design skills</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sustainable Particular skills/knowledge</th>
<th>Design Particular skills/knowledge</th>
</tr>
</thead>
<tbody>
<tr>
<td>LO: system thinking; however not explicit</td>
<td>LO: user based design is important</td>
</tr>
<tr>
<td>LO: understanding economic trends and government aspects</td>
<td>LO: framing problem definition and creating multiple concepts.</td>
</tr>
<tr>
<td>LO: Acquire a threshold level in three different disciplines involved in the solution.</td>
<td>LO: visual drawing</td>
</tr>
<tr>
<td>LO: transformation strategy knowledge</td>
<td>LO: forecasting, landside access, terminal design</td>
</tr>
<tr>
<td>LO: customer experience</td>
<td>LO: aerodynamics, mathematics</td>
</tr>
</tbody>
</table>

General remarks of the interviewees on the assessment in the design assignments is that it is important to involve all the teachers in the assessment and the alignment of the Rubric.
criteria. Most of the design projects need to be integrated as otherwise there is no solution possible. It is important to be aware that solutions in the design area, do not by definition need an interdisciplinary approach. Taking on board insights of other disciplines to resolve a design problem in a “designerly” way, is an activity within one disciplinary framework, according to the interviewees. General remarks in the sustainable area are that one should first know which learning methods are used, before the assessment methods are determined. Integration should be reflected in the individual contribution based on the diverse disciplines of group members interdisciplinary “attitudes”. Albeit the focus in sustainability is not necessarily on integration, it should be used as exit criterium. The difficulty with integration is that the content level becomes lower and does not compare to mono-disciplinary learning outcomes. Which makes the interviewees wonder how to get the best results of both worlds.

Discussion and Conclusion

The interviews performed in this research provided qualitative insight into two of the three key intertwined pillars of the interdisciplinary engineering education framework: vision and education. The results of the third pillar (facilitation) is not reported in this study.

The discussion in the Vision section shows that the staff’s primary interest in interdisciplinarity is not so much the definition, but rather whether the problem solving approach (reduction of complexity) results in some sort of scientific solution, given a particular context. In the problem definition section it is shown that within a framework students are stimulated to establish their own research questions and choose the best possible approach. The fact that this is done in interdisciplinary teams allows for a greater degree of freedom in coming up with appropriate integrated solutions. Yet at the level of assessment, we find that the ambitions in what students’ are to learn from working interdisciplinary (communication and group management) might contribute to the academic development of students. In the assessment, however, this is not supported as the assessment is done from a disciplinary perspective meeting the accountability criteria of disciplinary assessment standards. The latter is not unique as Boix Mansilla (2017) shows many teachers feel the students reasoning should be disciplinary grounded to meet quality standards.

Although the fact that the problems used in the courses are characterized by open problem definitions of real life, societal and complex problems and fulfill criteria of complex problems, they still could be solved within a single discipline. And above all, the students are not forced or informed about interdisciplinary approaches to solve such problems, thereby the solutions can still stay within the frame of one discipline.

The interviewees have defined interdisciplinary skills. Skills are related to communication and managing the group collaboration process, as well as content related, mostly focused on “about knowledge” gathering knowledge on specific domains relevant for the course. Most of these skills for interdisciplinary thinking are however not assessed. Meaning that the constructive alignment of the courses at hand is not fully aligned.

This brings us back to the research question of our research: “identifying how interdisciplinary education is structured in engineering education as perceived by the teachers and which key parameters can be identified to support future curriculum design”. Key parameters should include a clear vision on what defines interdisciplinary learning in a particular context, which problems are appropriate to come to solutions with an acceptable academic level and how can interdisciplinary thinking skills contribute to the academic development of students.

In this study we have realised a 1st exploration of a very small sample of teachers. At this point is therefore difficult to draw major conclusions. Yet it should suffice to start up the discussion on what educating students in interdisciplinary education means. The data richness shows there is a lot more to uncover in the additional interviews.
References


1 To protect the privacy of the participants we cannot be more specific about the gender or disciplinary area’s involved. The involvement across the faculties is fairly evenly distributed.

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Legitimating Engineering Education Research: A View from Sociology of Knowledge

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Abstract: Engineering education research has been frequently scrutinized to identify issues like who is producing research and with what methods. This paper is interested to explore what lies behind the level of interest in this topic. What explains the underlying focus on legitimacy – whether methodology, rigour, or who gets to call themselves an engineering education researcher? We analyze a selection of influential papers in this area. These aim to characterize the field of EER and make claims about what knowledge, and which knowers, are legitimate.

For our analysis we introduce new conceptual tools from the sociology of knowledge to explain some of the observed tensions between fields of education, engineering, and engineering education. Finally, we make a preliminary analysis of different boundaries drawn around EER in the US and the rest of the world.

Introduction

From the earliest establishment of formal qualifications in engineering, there has been a robust debate on how to improve educational practices. In due course, and at different points in different countries, reform efforts and their evaluation evolved into the idea of engineering education research as a distinct field of systematic inquiry. While this takes very different forms in different countries, there has been significant work to document the evolution of the growing field of engineering education research (EER), from analyses of publications (Korol-Ljungberg & Douglas, 2008), debates on methodologies (Case & Light, 2011; Malmi et al., 2018), definitions of rigour and quality (Borrego, 2007; Streveler & Smith, 2006) and characterization of research identities (Gardner & Willey, 2018).

What lies behind this intense focus on EER and its legitimacy, particularly in the eyes of the rest of the engineering education community? This paper argues that we need to draw on the sociology of knowledge to understand the competing claims about knowledge that underpin these debates around legitimacy. Specifically, we aim to identify the combination of epistemic relations (what type of knowledge) and social relations (whose knowledge) that exist in EER.

In doing so, we unravel central contradictions underpinning the tensions within EER which refer back to core questions from the sociological literature: What happens when a professional field shifts the basis of its knowledge claims? What are the implications for identity and legitimacy?

While in this literature there has been some focus on the nature and structure of the field of EER itself (Borrego & Bernhard, 2011) and some identification of the disciplines that are drawn on, there has been limited work on the nature of knowledge being produced using the sociology of knowledge. This is not to say that sociological studies of engineering education are new. There are a small and growing number of engineering education researchers that have studied core EER topics using sociology of knowledge. This includes topics ranging from the importance of both conceptual and contextual details in engineering design education (Wolmarans, 2016) to different representations of thermodynamics knowledge in engineering compared to science curricula (Smit, 2018). Other analytical studies have
characterized debates about the engineering curriculum and debates between theoretical knowledge and the requirements of professional practice (Case, 2014).

This paper shares with those studies an ontological perspective of social realism, and draws on similar theoretical approaches including Basil Bernstein’s sociology of education and knowledge and Karl Maton’s Legitimation Code Theory. Where it differs is in the unit of analysis: We focus on EER itself as a global field of knowledge production, and apply concepts from the sociology of knowledge to develop a systematic approach to understanding knowledge structures in EER.

We start by introducing key concepts from the sociology of knowledge: the core Bernsteinian notion of classification, moving on to LCT’s social relations and epistemic relations. In the process, we summarize past work that has characterized engineering and education as two distinct types of disciplines in terms of their knowledge claims, types of knowers, and functioning of disciplinary community. Second, we explain our methodological approach, which reviews and reinterprets influential studies that analyze the field of EER itself. Third, we represent our key findings in a chronological review of major arguments on the epistemic and social relations in EER. Finally, we conclude by drawing implications for actors within and without the field, and sketch out a future research agenda that includes an international comparative approach and an empirical component.

Conceptual framework – knowledge and knowers in engineering and education

Sociologists of knowledge often start by acknowledging that amidst much educational research, knowledge itself can often be taken for granted and thus neglected - Maton (2014) refers to this as knowledge-blindness. In this section we introduce three important ideas from the sociology of knowledge: The differentiated nature of knowledge; ways of characterizing academic fields and disciplines based on their organization of knowledge; and the types of knowers legitimated in different contexts.

The first important idea from the British sociologist Bernstein is that knowledge has different forms. Bernstein studied educational inequalities, starting with an analysis of class and sociolinguistics among working class children, later theorizing the nature of knowledge itself. Bernstein (1999, 2000) draws on Durkheim in distinguishing between everyday ‘profane’ knowledge that is limited to one context, and structured ‘sacred’ knowledge that is more abstract and generalized. The latter is academic knowledge. Bernstein further distinguishes between hierarchical knowledge structures that build sequentially as more advanced theories build on previous theories (physics is often presented as an archetype) and horizontal knowledge structures that build knowledge by adding new perspectives through specialized languages that do not necessarily build on each other (sociology and mathematics are common examples). Across all three types of knowledge (everyday, hierarchical, and horizontal) an important principle is the strength of boundaries - between everyday and academic knowledge, and between one knowledge structure and the others. Bernstein (2000) argues that power creates and legitimizes boundaries, and he uses the term ‘Classification’ to examine relations between different categories (whether knowledge structures, individual actors, or agencies).

The second important idea from Bernstein is that there are different modes of organizing knowledge. He defines singulatrs as individual bodies of knowledge (academic disciplines); region as the link between academic disciplines and fields of practice that constitute applied knowledge; and generics as a market-oriented principle for selecting knowledge in an ad-hoc way according to employer requirements for knowledge. In broad strokes, singulars have the strongest classification, as the original academic disciplines of sociology, economics, physics, mathematics, etc. have clear boundaries. Singulars are associated with a strong inward-focus and identities - knowledge for its own sake. In contrast, regions have somewhat weaker classification as they bridge a connection between academic disciplines and an
occupational field of practice. Finally, generics are extremely weak in their structuring of knowledge, and identities are malleable and constantly changing to market demands.

Given our interest in engineering and education, it is useful to characterize both fields using these concepts. Engineering is frequently referred to as an ‘old’ region (or cluster of regions), having developed and solidified its knowledge base in the 1800s and 1900s (Hordern, 2016; Muller, 2009). Engineering draws on a combination of hierarchical knowledge structures from mathematics and natural sciences, and formulates a clear professional identity and occupational structure through professional bodies. Education might also be considered a region, drawing on more horizontal knowledge structures from sociology, history, anthropology and political science (Hordern, 2017). There is weaker classification in education, as identities are weaker, and loyalties divided between the parent singulars (e.g. sociology) and the emerging region. A simple comparison can suffice: It is normal and even expected to introduce Bernstein’s work as coming from a sociologist of education, and yet it would be abnormal to think of engineering research conducted by a mathematician of engineering. Engineers have a stronger, more distinct identity than educators, which is a signal of stronger relations of classification.

What is interesting about engineering education is that it is the ‘illegitimate child’ of two regions. It has been suggested that we might term this a ‘second order region’ (J. Muller, personal communication, April 5, 2019). What is of interest is which elements, and with which weight, from each of the parent regions, come to determine the ‘rules of play’ in the offspring. As a region it faces inwards and outwards, but its inward facing is towards two parents, while outwardly it faces to the world of practice (the engineering classroom).

In all fields - whether singulars or regions - there are important differences between knowledge in research and knowledge in curriculum. Decisions must be made to select which aspects of knowledge are important, how to sequence those, what forms of pedagogic practice to use to communicate them, and what criteria to use to evaluate acquisition of that knowledge. This process of selecting, displacing, and transferring knowledge from one context to another (e.g. from research to curriculum) is called recontextualization (Hordern, 2018). This is of particular importance in regions, as by definition they involve recontextualizing knowledge from several different singular disciplines in order to prepare students for entry into the field of practice. This should resonate for engineering educators who have likely grappled with questions about the appropriate mix of mathematics, physics, computer programming and engineering design, and which should come first, second, and so on. Similar debates could be imagined among academics in an education faculty: How much sociology versus history of education? What research methods to emphasize?

The third major idea to make explicit is that knowledge is socially produced, but is not merely a social construction that can change on a whim. This is a distinct ontological assumption that characterizes the social realist group of scholars leading the Bernsteinian field of study (Case, 2013; Wheelahan, 2010; Young & Muller, 2010). Knowledge thus reflects the distributions of power among the groups that produce and legitimize it; but it also has its own intrinsic properties that are not reducible to power relations. The intrinsic properties of knowledge have already been elaborated in the discussion of everyday, hierarchical and horizontal knowledge structures, but can be more formally defined as epistemic relations between knowledge and its proclaimed object of study. Building on Bernstein’s work, Maton (2014) added a second dimension to this analytical approach, investigating the social relations between knowledge and its authors or subjects. This was important for Maton (2014, Chapter 3) in moving from study of how knowledge becomes curriculum (Bernstein’s emphasis) to studies of the production of knowledge itself, which is at the heart of this paper.

Different fields and disciplines have distinct approaches to knowledge production that can be characterized according to the strength of classification and framing of both their epistemic relations (ER+/-) and their social relations (SR+/-). Stronger epistemic relations (ER+) mean clear boundaries between academic subjects; while weaker epistemic relations (ER-)
indicate a blurring of boundaries. Stronger social relations (SR+) signal that particular groups of types of people have the power to define legitimate knowledge, while weaker social relations (SR-) have less emphasis on the type of knower. Maton (2014, p. 30) introduces these dimensions as two axes with quadrants representing four different ‘codes’ conveying the nature of power and legitimacy in different fields: knowledge, knower, elite and relativist.

Figure 1: Epistemic relations and social relations (Maton, 2014, p. 30)

This adds another layer to our analysis of education and engineering as the key constituent fields underpinning engineering education research. While both are regions with varying strengths of classification (stronger for engineering than education), adding the analysis of their social relations reveals the opposite: education has stronger classification of social relations (who is producing knowledge matters) compared to engineering (what knowledge is more important than who). Thus, education would be characterized as a knower code whereas engineering would be characterized as a knowledge code.

The numerous concepts introduced here are more than simply an elaborate exercise in categorization. Ultimately, we are interested in understanding the competing claims to legitimacy made by different actors (academic and professional) in engineering education research and how these relate to scarce resources - both material and status. The above analysis shows differences in the ‘codes’ governing engineering and education that suggest that when actors from one field attempt to engage in the other, their socialized assumptions and norms about what is considered ‘legitimate’ might be mismatched. What is of particular interest is how engineering education, as a new and hybrid field, negotiates the different codes and values of its of its parent regions. Beyond their epistemic and social relations, what characterizes engineering and education is the nature of their respective ‘regions’ - they draw on very different disciplines and are responsive to very different fields of practice.

Research design

The purpose of this paper is to theorize engineering education research in order to make sense of some of the complex contradictions at the heart of our field. Our main research question is: What is the basis of claims for legitimacy of knowledge in EER?

We adapt an approach used by Hordern (2018) to characterize the field of educational research in the United Kingdom in terms of singulars, regions and generics. Our approach is to review seminal studies in engineering education that seek to define or analyze the state of the field itself, including theoretical emphases and potential gaps. Our paper seeks out key sources where claims to legitimacy can be identified. In EER we note that there has been
substantial literature that makes such claims, and thus we focus on selected key journal articles on this topic. Our selection criteria sought to balance visibility and prominence (indicated by a high number of citations) with clarity and quality of argument (regardless of citations). The 15 articles we have chosen are indicated with an asterisk in the references section. Some of the papers are editorials, others are empirical studies. They also differ in their normativity: some explicitly say what the field of EER should be doing, and others conduct surveys of the field and use this as an evidential basis for saying what should be done. Our analysis reinterprets these existing studies through a sociological lens. We read and coded each paper for statements and claims that refer to either social relations (SR) or epistemic relations (ER). In our analysis, we use these fragments of data to characterize the field of EER as a whole, applying the Bernsteinian concepts of singulars, regions and generics to make sense of EER, similar to Hordern (2018).

Findings

Across the articles surveyed, we note an ongoing debate (especially in the US literature) on whether EER can be considered a discipline and/or a field. In this regard, it is interesting to note just how many articles draw on a single paper by Fensham (2004) for analyzing science education research. Fensham references (1) structural criteria, including journals, associations and conferences; (2) research criteria, including use of theory and methodology; and (3) outcome criteria in terms of impact on practice. We did not see evidence of a consultation of a broader literature on this topic.

In our analysis in this paper we disaggregate these into epistemic and social relations, although of course they are relatively intertwined in discourse. We find strong classification across both of these aspects, as will be shown below.

We also observe that much of the literature is produced by American authors, writing about the US in the Journal of Engineering Education (JEE), often analyzing JEE papers as a core part of the methodology. We note the international voices that have become visibly only later chronologically in this debate, and as such we mirror this in our narration. In the sections below, we attempt to tell a global story about EER chronologically from the 2000s onwards as these arguments intensified, but without homogenizing. We thus pay attention to who is speaking and writing and where nationally based structures play.

Epistemic relations

From the early 2000s in the US literature on EER, strong claims emerged around what might constitute acceptable research in the field. Streveler and Smith (2006) drew on a set of guidelines around ‘Scientific Research in Education’ to propose characteristics of what they termed ‘rigorous’ research in engineering education. Beddoes (2014) traced the way this framing was initially enthusiastically adopted especially by US researchers. For example, referencing the Fensham criteria outlined above, Borrego (2007) writes:

> It might be said that engineering education now has the infrastructure but not the research consensus to be called a distinct discipline. In this case, calls for rigor would be an appropriate next step to developing the field of engineering education. (p. 6)

Following some critique, initially more informally and especially in international conferences, the language on ‘rigor’ became less prominent and supplanted by an embrace of ‘methodological diversity’ (Koro-Ljungberg & Douglas, 2008). All the same, in Beddoes’ analysis, the focus was on ‘methodology discourses’ which were used to establish boundaries of what was legitimate work in the field. This also links to the observation by Borrego and Bernhard (2011) that a focus on empirical aspects of research is more prominent in the USA compared to Europe, not only in EER but in social science research more generally. Beddoes (2014) summarises:
The scholars cited in relation to the discourse of rigor are primarily from the United States, reflecting the fact that that is where the discipline-building efforts were originally based. Scholars cited in the methodological diversity section represent a more international group, coming from Europe, Australia, and South Africa. (p. 299)

Thus, it can be seen that the epistemic relations in this field are strongly classified, by reference to criteria for acceptable research, drawing on notions of scientific/rigorous research, and also by explicit reference to methodology. A crucial point here is the argument that EER needs to be its own distinct field separate from the broader field of education research. This is implicit in the statement by Lohmann and Froyd (2010):

Currently, conceptual and theoretical frameworks and research methodologies in engineering education research show considerable similarity to those of educational research in general; a condition that reveals its lack of maturity. (p. 9)

Other manifestations of the structure of scientific research are also used to support claims of legitimacy, as seen especially in the many bibliometric and related analyses that have been published on EER, identifying patterns of citation, but also of co-authorship and research funding (Wankat, 2004; Wankat, Williams, & Neto, 2014; Williams, Wankat, & Neto, 2018). Another significant aspect of this work is the content analyses that have been produced of topics of research. A prominent article in this regard announced a ‘research agenda’ for the ‘new discipline of engineering education’ (Adams et al., 2006), outlining five research areas.

All the papers referenced thus far are from the US literature and by US authors, mostly published in the Journal of Engineering Education. The international literature on EER is striking for its relative absence of claims for legitimacy in the European Journal of Engineering Education, which has a relatively global spread of authors as shown by Wankat et al. (2014), are occasionally made, but on a subtly different basis. Baillie and Bernhard (2009) presented a special issue of EJEE which sought qualitative papers with strong theoretical foundations and potential for impacting practice. They followed up (Bernhard & Baillie, 2016) with a publication which pointedly suggests that:

For the development of high-quality research in EER in the future we argue that it is necessary that the EER-community begin to negotiate criteria for quality. (emphasis added, p. 2378)

A recent bibliometric analysis by Malmi et al. (2018) further demonstrates the somewhat different conceptualization of the field outside the US in terms of the objects of knowledge:

Thus EER aspires to study the complex interactions between the central actors in the learning process, that is, students, teachers, teaching organisations and external stakeholders, as well as their relation to subject content. (p. 171)

Borrego & Bernhard (2011) attempt to bridge these differing claims for legitimation, noting firstly that the US community is more strident in its claims because of the more substantial resources at stake vis-a-vis NSF Funding. They note that while the US arguments have rested especially on methodology as noted by Beddoes, the European tradition for social research more generally privileges the significance of the problem context over the methodology. Other authors have lamented the way that this has resulted in ‘silos’ in the field (Jesiek, Borrego, Beddoes, Hurtado, & Rajendran, 2011).

### Social relations

The US literature on EER is especially notable for its explicit statements around the social relations to knowledge, i.e. who is qualified to undertake this research and to produce this knowledge. From the outset, the distinction between engineers (those with engineering degrees, not necessarily professional registered) and non-engineers is emphasized. For example, Wankat (2004) writes:
One remarkable aspect of engineering educators is their willingness to work with, listen to, and even reward non-engineers. The data in Table 4 shows that over the ten-year period 351 of the 1,470 authors (23.9 percent) did not have an engineering or computer science degree. (p. 18)

It is perhaps unsurprising that it is assumed that those leading EER will be engineering educators, typically holders of engineering qualifications themselves. From the outset there were disagreements over the role of collaborators with social science expertise.

However, in the US with the need to establish legitimacy for this field within engineering as such, there is a strong emphasis across these debates on who is doing EER and who are the leaders in the field. With the significant role of voluntary organisations in US public life, most prominently the ASEE in this context, the participation of office-bearers in such organisations was considered important. Thus, for example, Streveler and Smith (2006) make a claim for the legitimacy of the argument for ‘rigorous’ research based on the constitution of the group that authored it:

The RREE Executive Committee, a multidisciplinary group composed of members of the American Society for Engineering Education (ASEE), the American Educational Research Society (AERA) Professions Education Division, and the Professional and Organizational Development Network in Higher Education (POD), tackled this problem when revising RREE for 2005. (p. 104)

However, early on, recognition was made that the training held by engineering educators in their formal studies was not necessarily appropriate for conducting education research. Thus, claims were made that EER researchers need to be adopting new approaches. Baillie and Douglas (2014) are gently encouraging on this score, noting:

Moving into a new area of research, especially an interdisciplinary area and from technical to social research data, can be daunting. (p. 1)

Borrego and Bernhard (2011) are clear that engineering training is not suitable for conducting education research:

At present, the majority of scholars who identify with the emergent field of engineering education have been formally trained as engineers and have instructional responsibility for engineering students, or they work closely with engineering educators in a staff/faculty development role. Engineering educators understand the engineering content on a deep level, have strong pedagogical content knowledge regarding teaching and learning in their specialty, and are emotionally invested in engineering educational settings (as opposed to general education) (Borrego & Newswander, 2008). But they often find that research approaches suitable for their technical research are not as suitable for their educational studies. (p. 32)

In this overview of the US claims for legitimacy of EER, we can see that the social relations are strongly classified. This becomes more complex when researchers started trying to strengthen international links in the field, most especially through the initiative Advancing Global Capacity for Engineering Education Research (AGCEER). Borrego and Bernhard (2011) note that the establishment of departments of engineering education were likely to be of more significance in the US where such structures are important for legitimating research areas. Reflecting further on the AGCEER, Jesiek et al. (2011) note:

Through a series of special sessions at engineering education conferences worldwide, one goal of the initiative was to cultivate a global network of engineering education scholars and practitioners, including to identify infrastructures needed to sustain such a community [8, 9]. Yet as we report elsewhere, these sessions revealed that many advocates of engineering education research remain preoccupied with the field’s sustainability in local contexts. (p. 77)
In our review of the literature we did not find many normative statements around who does EER from communities outside the US, and would therefore judge it as somewhat weakly classified in this domain.

**Discussion**

EER has taken quite a different shape in the US as compared to the rest of the world, with strong classification both in terms of its epistemic relations and its social relations. Referring back to Maton’s (2014) four quadrants, this would place EER in the US as an ‘elite’ code (ER+, SR+), ‘where legitimacy is based on both possessing specialist knowledge and being the right kind of knower’ (p. 31). However, this characterization comes with an inherent tension, as the right kind of knower in EER is one with an engineering background, while the right kind of knowledge is rigorous by educational research standards and still recognizable by the rest of engineers. Lohmann and Froyd (2010) capture this well:

> Engineering education research has become an established field within the last decade, although its recognition and acceptance within the broader engineering community remains a challenge. (p. 11)

What explains the major difference between the US and the rest of the world? First, the stakes are higher: Differentiating *engineering* education research from simply educational research is important in order for researchers to gain access to earmarked funding from the NSF for this field. Second, there are organizational structures and professional identities in the US that are more explicit: departments of engineering education with explicit graduate programs for EER. These can be understood both as responses to the resource opportunity mentioned above, as well as reflections of the broader culture and institutions of American higher education (Abbott, 2002). As far as the relative absence of studies staking claims for EER in other countries, this can be partly explained by a lack of resources – the limited funding is available is mostly directed to conducting EER studies rather than internally focused questions about the state of the field itself. There are important exceptions analyzing, for example, the evolution of EER in Europe (Williams & Neto, 2018) and the recent special issue in EJEE on the coming of Age of EER in Europe (Bernhard, 2018), but these show more fragmentation and diversity compared with the field in the US.

What are the implications of this schism in the global field of EER? Looking at the US, there is a risk of EER becoming completely insulated from other disciplines if it continues to take on features of a ‘singular’ by constructing such strong boundaries. If the elite code dominates, then social scientists and education scholars alike may be blocked from contributing (and critiquing) EER. Also, the production of PhD graduates in engineering education introduces new dynamics, as these newly minted doctorates seek employment - both in EER departments and other disciplines, and in US and abroad. The opportunities presented to them, and the choices they make, could have an important influence on the strength of boundaries in the field. A recent paper by a group of Assistant Professors with PhDs in engineering education brings to life some of these identity dilemmas and disciplinary loyalties to life (Kirn, Huff, Godwin, Ross and Cass, 2019).

Countries outside the US might be tempted to follow the American model, but our analysis suggests caution and perspective: some of the elements are culturally embedded in the higher education system, and others can be problematic from a knowledge perspective.

**Conclusion**

Engineering education research exists in a dynamic tension with its parent regions of engineering and education. Proponents and early champions of the field have made particular claims about the type of knowledge produced by EER, and about who should legitimately be able to contribute. Numerous other studies have looked at this topic, often using bibliometric approaches that quantify the number of publications by different types of authors on different topics within EER. This paper has taken a different approach: a
sociologically framed discourse analysis. We have argued that the sociology of knowledge offers tools for analyzing the nature of the field, by examining the types of claims made. In particular, we use social relations and epistemic relations to map the historical trajectory of discourse. In doing so, we found major differences between the US and the rest of the world that have important implications for how researchers conduct research, present their findings, and represent themselves and their work in different arenas. This paper thus offers a first step in a new line of theoretical inquiry into the structures that underpin and constitute engineering education research. Some of the topics that could be explored comparatively include the ranging disciplinary emphases of EER in different countries; the links between resources and organizational structures; and the moral discourses underpinning different claims for legitimacy in different EER camps.

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(Re-)validation of a standardised test instrument in a different national context

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Abstract: The development and application of standardised test instruments such as concept inventories have fostered the discussion on and innovation of teaching and learning. This paper addresses the necessity of validation studies when using a concept inventory in a different national context than the one it was developed in. The revalidation procedure is illustrated using the Concept Assessment Tool for Statics (CATS) in a mixed-methods approach based on (qualitative) student and expert interviews, as well as (quantitative) factor analysis, item response theory, classical test theory, and correlation analysis with exam scores. The results of the quantitative analysis are comparable to prior validation studies performed in the original context. The qualitative analysis raises a few issues but allows for the general conclusion that the CATS may be used and interpreted in the German higher education engineering context as a measure for conceptual understanding of statics.

Introduction

Like any measurement instrument, conceptual tests must measure what they are supposed to measure, and they must do so to a certain degree of accuracy. Whenever a test is applied in a different context than the one for which it was designed, the question should arise whether it still functions as expected. Education researchers are often using tests, for example, to investigate the effectiveness of teaching. Instead of exams, which differ among courses and cohorts, standardised test instruments are often chosen to make use of a common scale. The prefix “standardised” states that the test given to all groups of participants as well as the administration conditions and grading system are the same. Concept inventories (CIs) are standardised tests which focus on understanding of one or several related concepts. In Science, Technology, Engineering and Mathematics (STEM) education research, they are often used to compare different courses or teaching methods with respect to understanding of relevant concepts or as formative assessment to reveal conceptual difficulties on which the instruction should focus. The Force Concept Inventory (FCI), developed in 1992 by Hestenes and Halloun (Hestenes et al., 1992), has probably been the most successful and most widely used CI in physics education research (Engelhardt, 2009). The success of the FCI sparked the development of CIs in other disciplines, predominantly in the US. As of today, more than 150 grants have been awarded by the National Science Foundation (NSF) to projects mentioning the terms “concept inventory” or “concept inventories” in their project titles or abstracts (National Science Foundation, 2018). If possible, existing CIs should thus be used instead of "reinventing the wheel".

The adaptation to a different national context often requires a translation which should be carefully validated. For example, Benegas and Flores (2014) used a Spanish translation of the "Determining and Interpreting Resistive Electric Circuits Concepts Test" (DIRECT) (Engelhardt and Beichner, 2004) that was validated by experts in the field. Mazak et al. (2014) developed a Spanish version of the Concept Assessment Tool for Statics (CATS) (Steif and Dantzler, 2005) and the effect of the translation on performance was investigated in a small-scale control vs. experimental group study. But differences due to national context are not
limited to language. Incompatibilities in terms of notations, conventions or course content may also affect the validity of the test result interpretation. Even for identical course content, different learning goals might be pursued. Last but not least, distractors might be culture-dependent. The revalidation process must thus go beyond language and translation issues.

The revalidation procedure suggested by the authors will be illustrated using the CATS. This test was first published in 2005 (Steif and Dantzler, 2005) and has been revised through several versions (Steif and Hansen, 2007). This paper addresses version 4. The CATS developers state that "[t]he underlying theoretical construct of this instrument is 'statics conceptual knowledge.'" (Steif and Dantzler, 2005, p. 369). A more detailed interpretation guide with respect to the score range is not given. The main purpose of the CATS is identification of student misconceptions to inform instruction and misconception research, while the assessment of instruction poses a secondary purpose (Steif and Dantzler, 2005). The proposed time limit is 60 minutes, which was found to be "plenty of time in which to complete this test" (Steif and Hansen, 2007).

The developers designed the CATS to test nine different concepts with three multiple-choice questions (items) each, evenly distributed over the resulting 27-item test instrument. By measuring the understanding of the nine concepts, the CATS is supposed to measure one higher-order single construct, i.e. ‘conceptual understanding of statics’. Therefore, the scores on all items may be added to form a single test score. Figure 1 illustrates the theoretical structure of the instrument. The item numbers indicate their sequence on the administered test.  

**Research Questions**

If the German CATS version is administered in the German higher education context, ...

1. ... is the total score a valid interpretation of the level of conceptual understanding of statics?
2. ... do the proposed concept subscales provide valid and reliable information on student understanding of those concepts?

**Theoretical Framework**

This study is supported by classical and modern test theory which provide a variety of methods (see Methods section). Validity and reliability are central concepts of test theory. Validity addresses the issue of measuring the intended construct, while reliability refers to the degree of accuracy of the measurement. There are several aspects which might pose a threat to validity, for example, if constructs tested by single items are unrelated to the overall construct.

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1The reader should be aware that in other literature on the CATS, the authors often refer to the item sequence ordered by concept (as ordered in Figure 1 from left to right).
targeted by the test, or if items are systematically misinterpreted. Random misinterpretation of items negatively affects reliability.

The statements “the test is valid” or the term “validity of a test” can be found in many publications. Care must be taken as they falsely suggest that validity is a property of a test. Instead, validity refers to the interpretation of test scores for a predefined purpose. “The test is valid” is a mere shortcut for saying that the interpretation of the test scores for a predefined purpose is valid, if the test was administered in a predefined way. Consequently, the interpretation and the purpose must both be made explicit before any investigation on validity can be commenced (American Educational Research Association et al., 2014). According to Crocker and Algina (1986), validation is “the process by which a test developer or user collects evidence to support the types of inferences that are to be drawn from test scores”. Below, we will describe the pieces of evidence that can be collected to support or rebut a validity claim.

Methods

The revalidation is based on the framework proposed for the validation of CI-claims by Jorion et al. (2015) and the procedure for development of a standardised test described by Adams and Wieman (2011). Jorion et al. (2015) suggest to apply classical test theory (CTT) and item response theory (IRT) methods to the entire test to determine problematic items, followed by a structural analysis with problematic items removed. The structure of the instrument shall be first explored with exploratory factor analysis (EFA), followed by an optional confirmatory factor analysis (CFA) or diagnostic classification modelling (DCM). A categorical judgement scheme is provided together with judgement rules to assess the results. Adams and Wieman (2011) additionally suggest correlations with course outcomes such as exams to add evidence that the intended construct is targeted by the test.

These rather quantitative approaches are complemented by qualitative investigations. Adams and Wieman (2011) propose to “[e]stablish topics that are important to teachers” and to “[c]arry out validation interviews with both novices and subject experts on the test questions” (Adams and Wieman, 2011, p. 6). These primarily development-related investigations are also relevant for validation in a different national context. They touch on the aspects of possible differences in terms of course content and learning goals, as well as language, notations, and conventions.

Neither of the mentioned frameworks addresses the special issue of a different national context, but the general goal is the same: making sure that the instrument measures the intended construct. Therefore, most of the suggested methods apply. In addition, a language analysis will be performed, inspecting the differences introduced by the translation and evaluating those in light of the other differences due to national context. An overview over the various analyses is provided in Table 1, stating the purpose and the implementation. A detailed description of the statistical methods cannot be provided within the limited scope of this paper. Please refer to the frameworks of Adams and Wieman (2011) and Jorion et al. (2015) or any standard textbook on test theory (e.g. Crocker and Algina, 1986).

Description of the data

Qualitative data

We interviewed twelve instructors from six different German institutions. As preparation for the interviews, the experts were asked to work through the test. The following are examples of questions from the interview protocol, which served to investigate to what extent experts agree that the test measures the proposed construct:

• Do you expect your students to be able to respond correctly to the items?
• Which concepts do you think does the test address?
• Which central concepts are missing and which ones would you replace or dismiss?
• How do you assess the choice of distractors? Do you recognise the underlying misconcep-
### Table 1: Overview of type and purpose of collected evidence for validity

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Purpose</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Qualitative</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Content</td>
<td>Are the concepts tested by the items relevant for local instructors? Do they reflect important learning goals?</td>
<td>Textbook analysis, description of the course, expert interviews</td>
</tr>
<tr>
<td>Language</td>
<td>Did the translation introduce deviations from the original formulations and terms, which changed important aspects of the item?</td>
<td>Item-by-item comparison of translation to original</td>
</tr>
<tr>
<td>Item interpretability</td>
<td>Can local students interpret the items correctly so that the item can measure the intended construct? Do experts evaluate the items as interpretable?</td>
<td>Think-aloud student interviews on selected items, expert interviews</td>
</tr>
<tr>
<td><strong>Quantitative</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CTT - item statistics</td>
<td>Determine problematic items in difficulty and discrimination</td>
<td>Apply judgement scheme to difficulty and discrimination indices</td>
</tr>
<tr>
<td>- reliability</td>
<td>Is the scale internally consistent? Do all items add to the reliable measurement of the same overall construct?</td>
<td>Cronbach’s $\alpha$ (of total score and of scores with item $i$ deleted).</td>
</tr>
<tr>
<td>IRT</td>
<td>Do the items fit the assumption that the probability of a correct response to an item is low for students of low ability and high for those of high ability?</td>
<td>Visual inspection of item characteristic curves</td>
</tr>
<tr>
<td>Structural Analysis</td>
<td>How many subscales does the instrument consist of? Which items group together on the same subscale?</td>
<td>Exploratory Factor Analysis</td>
</tr>
<tr>
<td>Exam correlations</td>
<td>Exams measure a related construct. Positive correlation adds evidence to validity.</td>
<td>Pearson’s $r$ between CATS and exams</td>
</tr>
</tbody>
</table>

The interviews were recorded, transcribed, and coded with respect to statements addressing various aspects, such as individual items, the nine CATS concept categories, measurement of expert-like thinking, or expectation of student performance on the CATS. Some of the codes were set a priori, others emerged while reading the transcripts. The range of different responses was very broad, so that not all aspects can be discussed here in detail.

In addition to the experts, 16 students at post-instruction level participated in individual think-aloud interviews. The focus of the interviews was on whether the items are understood as intended. The sample was heterogeneous in terms of the recorded characteristics: gender,
study program, native language, previous education, and their final high school grade. They were all shown the instructions at the beginning of the CATS followed by two to six selected items until the announced time limit of 30 minutes was reached.

Quantitative data
The CATS data was collected in a large introductory mechanics course at Hamburg University of Technology (TUHH) from 2005 to 2016, resulting in a total number of $N_{\text{All}} = 4068$ student test data, after removing unserious data with less than nine responses. Students are mostly native German speakers which is also the course language. The test administration was done in class in a paper and pen format. The researchers were not in charge of the course. As course time is sparse, the instructor agreed to provide 45 minutes. The net time on the test was thus 35 minutes, which is substantially less than the proposed 60 minutes. This is expected to have a negative impact on validity. The data indeed consist of many blank responses on the late items, up to 25% on the last item. They will be graded as incorrect, even though it is unclear if students even got a chance to view the item. We must hence assume that the later items will be overestimated in terms of difficulty. To estimate the extent of this effect, we additionally run the quantitative analysis on a subset of the data, consisting of only those students with no blank responses ($N_{\text{noBlanks}} = 2010$). Note that this result will also be biased, though in a different way, because only certain types of students show this kind of test-taking behaviour, i.e. the sample is more homogeneous than the population.

Most of the quantitative results will be compared to the results presented by Jorion et al. (2015). Their sample of $N = 1372$ students consists of aggregated CATS data provided by instructors from about 20 institutions. The aggregation results in high heterogeneity with respect to e.g. pedagogy, courses, or time and method of administration.

Results
In this section, we will present selected pieces of evidence gathered. The qualitative analysis encompasses content, language and item interpretability. The quantitative analysis is mainly based on the framework proposed by Jorion et al. (2015), including CTT, IRT and EFA, and enhanced by a correlation analysis with exams as suggested by Adams and Wieman (2011). The sequence of presentation follows Table 1.

Content
To assess whether the CATS tests concepts which instructors consider relevant for conceptual understanding of statics, a content analysis was conducted based on textbooks, course description and twelve expert interviews with instructors from six different German institutions.

The content analysis showed that the CATS does not address any content which is not introduced by the investigated course, but it does not necessarily address the most important concepts. For example, the correct labelling of forces on a free-body diagram was seen as less important by some experts than the prior step: defining where to separate the bodies. Also, while different types of supports are of course introduced, the focus is different between German and American engineering mechanics instruction in terms of the degree of abstraction in the depicted mechanical systems. US textbooks prefer a more realistic representation, while most German textbooks traditionally use more abstract models, with distinctions made only with respect to the number and type of constraints imposed by the support (as shown in Figure 3 (b)). Consequently, the German students are not familiar with roller and pin-in-slot joints as used in the CATS and thus may have to take an additional mental step to translate the problem into the familiar abstract language.

The expert interviews furthermore revealed that being able to solve any complex statics problem systematically is a central learning goal. In some experts’ opinion, the CATS and the conditions of test administration do not provide the appropriate frame for applying the systematic approach. For instance, one expert (E4) stated that

"The test requires too much intuition for my taste."
When asked what he meant by "intuition", he elaborated:

"Intuition comes when I have solved 20 of such problems or after I have served as a teaching assistant on this topic and have been asked questions which surprised me and I had to think about it myself and question my own... yes, constructed knowledge and connections, then it becomes something like intuition."

If given the appropriate amount of time, however, he would expect his students to solve the questions using the systematic quantitative approach learnt in class. What E4 describes as "intuition", we would call deep or expert-like understanding, which is indeed what the CATS intends to measure. The statement can thus be seen as supporting evidence for validity with the problem being only the time constraint.

The expert interviews were difficult to conduct. As a CI should focus on a limited number of central concepts, the content of an entire course necessarily exceeds the concepts addressed by the CATS. Many of the experts struggled to (1) think in terms of concepts instead of content, (2) see value in a test that does not cover all the course contents, (3) see the different purpose of the CATS compared to an exam, and (4) refrain from criticising the items on a very detailed level. In order to obtain useful and high quality data, it is therefore essential to communicate the purpose and intended scope of the instrument and the focus of the interview. At the same time, the experts' responses must not be biased. Finding the right balance between information and influence is key.

Language

The language analysis revealed three main aspects which were affected by the translation: (1) the translated version was making an increased effort to formulate the items precisely and make them "bullet-proof", (2) unfamiliar terms and notations were paraphrased and explained, and (3) conventions were considered.

Nearly all of these adaptations were implemented at the expense of creating more text including more complicated sentences. The construct "reading comprehension ability" becomes increasingly relevant with more complicated phrases, a construct which is not the desired one to measure. In combination with a tighter time limit, this can have a negative impact on the observed performance and thus on validity. As an example for aspect (1), the original question on all 'Pin-in-slot joint'-items ignores that one distractor also includes a couple (see Figure 2). In the translated version, the couple is considered for precision, resulting in a much more

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2The correct response is (b).
complicated sentence\textsuperscript{3} (also due to the more complicated German grammar).

The changes were in part influenced by the instructors who had to give permission to administer the test in their courses. Their advice was valuable in terms of learning goals, conventions, and notations, but their tendency to phrase test questions (overly) precisely introduced a higher level of complexity. This tendency is probably culturally influenced, driven by the concern of legal consequences in case of ambiguously phrased exams.

**Item interpretability**

Some of the problems anticipated by the experts, such as interpreting arrows as resultant forces, could be confirmed in the student interviews. Still, most of the selected items were correctly interpreted by the students. Especially the most problematic item in the quantitative analysis, item 20, was most often correctly interpreted. The only misinterpretation that did occur was harmless in that it did not affect the students’ response. The remaining problems to find the correct response were due to lack of conceptual understanding of statics, and therefore a positive indicator for validity.

**Classical Test Theory (CTT)**

According to the scheme proposed by Jorion et al. (2015) (see Table 2), all item difficulties shall lie between 0.2 and 0.8 for an excellent evaluation of item difficulty statistics. For a good evaluation, up to three items may lie outside of this interval. Items 17 and 20 were too difficult in both data sets, “All” and “noBlanks”. As the evaluation of discrimination is determined only by the worst item in the judgement scheme, the result is only average because of the very poorly performing item 20. Removing this item results in good (all item discriminations > 0.1) to excellent (all item discriminations > 0.2) evaluations.

Reliability of a scale is often assessed with Cronbach’s $\alpha$, which is based on the concept of internal consistency. It assumes that all items measure one single construct. A perfect correlation of 1.0 would indicate that a single item would be sufficient to test the construct. With supposedly nine concepts to test for and a reasonable result for the proposed concept structure (see factor analysis below), a value close to 1.0 is not expected. Furthermore, it should be inspected whether the internal consistency improves or stays the same if an item $i$ is removed (test if $\alpha_{i-} \geq \alpha$). In either case, item $i$ probably measures a different construct or is badly phrased. We found values slightly smaller than the reference, but still in an acceptable good range from 0.80 to 0.81. We furthermore found that $\alpha_{i-} > \alpha$ for item 20.

**Item Response Theory (IRT)**

IRT is a probabilistic test theory. An item’s characteristic curve (see Figure 4 left) shows the estimated probability $p$ for a correct response depending on the person’s ability (in terms of the construct being measured). Common models are based on the logistic equation which allows to restrict the estimated curves to the interval $[0, 1]$, as required for probabilities. For both our data sets, “All” and “noBlanks”, a three-parameter logistic (3PL) model fit the data best.

\textsuperscript{3}“Welche Richtung hat die Kraft (bzw. welchen Drehsinn hat das Moment), die (das) von der Aussparung auf den Stift im Punkt A ausgeübt wird (werden) [...]”
according to the Akaike information criterion (AIC)\(^4\). The three parameters allow for variation among the items in (1) difficulty, (2) discrimination and (3) guessing probability. Contrary to Jorion et al. (2015), where the two-parameter logistic (2PL) model fit best, we must hence conclude that guessing plays a role in our setting, at least for some items. This may be caused by the tighter time constraint, or it may have cultural reasons.

In the adopted evaluation scheme, the criterion is whether "all items fit the model". Unfortunately, Jorion et al. (2015) leave room for interpretation when this is not the case anymore. We thus define acceptable guessing asymptotes to lie in the interval \([0, 1/3]\), which corresponds to less than two obvious distractors. Furthermore, the probability for high ability persons shall be \(p(4) > 0.8\). Only item 20 does not fit the model in this sense because it is too difficult and must be declared as a problematic item with \(p(4) < 0.8\). This result is in accordance with Jorion et al. (2015) (where item 20 is called Q26). In contrast to the CTT results, item 17 is not problematic when applying IRT. Item 23 has a noticeably high guessing probability, close to but not quite reaching the critical value of one third. Unlike the test information function reported by Jorion et al. (2015), which peaks near Ability \(= 0\), the test information function on the right side of Figure 4 shows that the CATS is most informative for higher abilities in the range between 1 and 2. This indicates that the level of difficulty is slightly too high for the population.

Factor Analysis

A factor analysis is applied to investigate the structure of a test scale and check for subscales. The problematic item 20 is omitted. As in Jorion et al. (2015), eight factors were suggested by parallel analysis, regardless of the data set. The exploratory factor analysis was performed with the oblique rotation method 'direct oblimin'. Oblique rotation allows the factors to correlate, which is an appropriate assumption here due to the single scale of conceptual understanding of statics and it’s high internal consistency. As in Jorion et al. (2015), low factor loadings of less than 0.30 were omitted.

Six factors could be identified to align with the proposed concepts (seven in the noBlanks data set). A concept was determined as identified, if at least two concept-related items and no unrelated items load onto the same factor. The concept 'Loads at surfaces with negligible friction' was only identified in the "noBlanks" data set, the concepts 'Representation of loads

\(^4\)The AIC considers not only the goodness of fit, but also punishes high complexity of the model. The introduction of another parameter must hence result in a substantially better fit
Table 2: Evaluation of psychometric analysis (Jorion et al., 2015, according to scheme suggested in Table 11). E = excellent, G = good, A = average, P = poor, U = unacceptable (did not occur). Numbers in brackets indicate numbers of items which did not comply with the standards. (*corrected error in reference)

<table>
<thead>
<tr>
<th>Analysis</th>
<th>Data set</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>All noBlanks</td>
<td>Jorion et al. (2015)</td>
</tr>
<tr>
<td>CTT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item stats.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Difficulty</td>
<td>G .11 to .71</td>
<td>G .11 to .71</td>
</tr>
<tr>
<td>-Discrimination</td>
<td>A .04 to .45</td>
<td>A .08 to .69</td>
</tr>
<tr>
<td>(-Discr. w/o item 20)</td>
<td>G*.15 to .45</td>
<td>E .27 to .45</td>
</tr>
<tr>
<td>Total score reliability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-Cronbach’s $\alpha$ total</td>
<td>A .80 G .81</td>
<td>G .84</td>
</tr>
<tr>
<td>-Cronbach’s $\alpha_{-i}$</td>
<td>G (1) G (1) G (3)</td>
<td></td>
</tr>
<tr>
<td>IRT</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Item measures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-All items fit model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2PL</td>
<td>E (1) E (1) E (2)</td>
<td></td>
</tr>
<tr>
<td>3PL</td>
<td>E (1) E (1) -</td>
<td></td>
</tr>
<tr>
<td>Structural analysis</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Exploratory FA</td>
<td>A (7) G (5) G (5)</td>
<td></td>
</tr>
</tbody>
</table>

at connections’ and ‘Equilibrium’ could not be identified by the EFA in either data set.

According to the evaluation scheme in Table 2, the EFA results are evaluated as average with seven items that did not load onto the expected factors. If student data with blank responses are removed, the result compares to the reference.

Exam correlations

Positive correlations with other instruments measuring a related construct add evidence to the validity of the investigated instrument. As exams are not focused on conceptual understanding to the same extent as the CI, and also cover a broader scope of content, the correlation is not expected to be very high. The correlations (Pearson’s $r$) between the CATS as post-test to statics instruction and the statics exams (midterm and final) were both found to be $r = 0.5 \pm 0.1$, which is comparable to results from Steif and Hansen (2006).

When correlating scores from standardised tests with those from exams, care must be taken to not put too much weight on a single observation, because exams necessarily differ each year. If possible, data from multiple cohorts should be analysed. Depending on local data protection protocols, obtaining and using exam data for research may be difficult. In these cases, gaining validation evidence from correlations with exams may not be possible.

Conclusions

The qualitative analysis shows that the content is covered by instruction, and that most (but not all) items are interpretable to students and experts. The selection of concepts was only in part confirmed by the experts to address the most central ones. Applying the quantitative framework by Jorion et al. (2015) reveals that the most problematic item is the same in the German and the US context, but our data show a slightly weaker performance on structure, reliability, and discrimination than the reference. Possible reasons might be that the German
students are less familiar with the representation, that the translated text is more complicated than the original, or that less time was given. Regarding the latter, filtering the data so that no assumptions need to be made on the meaning of a blank response leads to only slightly better psychometric results. Furthermore, Steif and Hansen (2007) found that "[t]here is no noticeable pattern in the variation of mean scores for the remainder of examinees with time above 25 minutes". Even though these results stem from the US context and are not necessarily applicable to the German context, they hint that if there is an effect of giving less time on the test compared to the suggested hour, it may be less serious than expected.

Overall, the collected evidence suggests that the CATS total score can be interpreted as a measure for conceptual understanding of statics for the intended purposes in the German higher education context. For the concept subscales, this interpretability applies only in parts.

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References


The CECI - Interview-based development of items for a control engineering concept inventory

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Abstract: The discourse about teaching in control engineering would greatly benefit from having a common instrument to measure the success of teaching. This can be achieved by a concept inventory. In the process of developing the CECI - Control Engineering Concept Inventory - first drafts of items were exposed to students in interviews. The interviews yielded insights into student understanding, the process of developing items along with the interviews, and the role of example systems in qualitative questions. These findings are transferable to other domains of engineering, they are not only relevant to control engineering instructors but to everyone involved in teaching engineering.

Introduction

Control engineering is an important part in many engineering curricula as can be seen by the importance of automation in the industry. Many students at Hamburg University of Technology (TUHH) seem to have problems learning the basic concepts of control engineering in an introductory course (Eichler et al., 2013). There is no indication that this is significantly different at other universities.

Furthermore, conceptual knowledge is, along with factual and procedural knowledge, important for proficiency in a domain (Bransford et al., 1999). As procedural and factual learning is already rewarded in engineering education (Felder and Brent, 2005; Elby, 1999), it is especially important to foster the teaching of conceptual understanding. All the more so as problem solving, a very important skill for engineers, is negatively influenced by a lack of conceptual understanding (Hestenes and Wells, 1992).

A way to improve student conceptual understanding in control engineering is to try different methods of teaching and measure the gain in conceptual understanding. These measurements can be done by a concept inventory. A concept inventory is a standardised multiple choice test, which uses qualitative questions to measure conceptual understanding/expert-like thinking (Adams and Wieman, 2011, they refer to concept inventories as formative assessment of instruction). A concept inventory for introductory control engineering courses could spark the discourse about teaching in control engineering across institutions as the Force Concept Inventory (Hestenes et al., 1992) did in physics education (Libarkin, 2008).

The research presented in this paper is part of a dissertation project. The aim of the project is to develop the Control Engineering Concept Inventory, the CECI. There have been at least two attempts to develop a concept inventory in control engineering: One was successful but the concept inventory was developed for evaluating a certain course making it too narrow for widespread use (Bristow et al., 2012) and the other was never finished (Lundberg, 2012). The project behind this paper and its motivation are described in more detail in Kieckhäfer et al. (2017).
As part of the development of a concept inventory, one needs to draft items and test them. In the early stages of an item, this is often done in interviews with students (Adams and Wieman, 2011). So the main objective of this qualitative study is to test and further develop first items for the CECI. A thorough analysis of the reliability and the validity of the items comes in a later stage of the dissertation project. A second objective is to get deeper knowledge of student understanding in control engineering, which will help with the development of further items.

The analysis of the interviews is still in progress. Therefore, the result section focusses on the use of example systems (systems that are used to illustrate the item at hand) and their impact on qualitative reasoning, the development of an item from scratch along the process of conducting the interviews, and two specific patterns of incorrect reasoning, which are relevant in all engineering disciplines, not only in control engineering.

**Theoretical framework**

Conceptual understanding has been studied in the context of introductory science and engineering courses for some time. Originating in the field of physics, systematic student difficulties in various subfields have been identified through student interviews and written tests (McDermott and Redish, 1999). Similar work has since been done in the other sciences and in engineering. Generally, these studies have identified specific conceptual difficulties that are prevalent and persistent after traditional instruction in the respective subjects. Based on these results, concept inventories have been developed.

Especially the following tenets are important for the research presented in this paper: Measuring conceptual understanding is a good way to gauge student understanding (Mazur, 1997, pp. 5-7). Concept inventories, like the Force Concept Inventory (FCI, see Hestenes et al., 1992), are widely used instruments to measure conceptual understanding (Libarkin, 2008). As teaching is essentially helping student understanding, concept inventories are one possible measure for the quality of teaching (Evans et al., 2003). Going further, it is possible to compare courses and teaching methods using concept inventory scores (Hake, 1998; Garvin-Doxas et al., 2007).

**Methods and implementation**

Interviews were used to expose first drafts of items to students. This section describes how the interviews were conducted, what the population was, what items were used and how the interviews were analysed.

**Interviews**

In each semi-structured interviews, a student was exposed to about four of the six different items. The planned duration of the interviews was about 30 minutes. To get the best insight into the thoughts of the students, they were asked to think aloud and follow-up questions were asked whenever the interviewers deemed it necessary. Due to the exploratory character of the study, it was not possible to state follow-up questions beforehand. The tabletop with the sheets of paper with the item and the hands of the students on it were videotaped, so that it was possible to reconstruct not only the spoken word but also the timing of writing and gestures. All students agreed to the videotaping and were informed about their rights according to the European General Data Protection Regulation (European Union, 2016). After the interviews, only pseudonyms were used. As incentive, the participating students were offered one on one tutoring after the interview. The interviews took place after all topics relevant for the items in the interviews had been covered in the course the students were recruited from. In an interval of five weeks, 11 interviews with 11 different students took place. All interviews were conducted in German and in most of the interviews, two interviewers, the first author and a varying second person, were present.

**Population**

The students all were enrolled in the the course ‘Introduction to Control Systems’ at TUHH. This course is taught in the fifth Bachelor-semester and is taken by around 500 students from
Table 1: Items used in the interviews

<table>
<thead>
<tr>
<th>Item</th>
<th>Short description</th>
<th>Interviews</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Controlling the temperature of a soup with P-control</td>
<td>1, 2, 3, 4, 6, 7, 8, 9, 10, 11</td>
</tr>
<tr>
<td>2</td>
<td>Controlling the water level of a tank with P-control</td>
<td>5, 6, 7, 8, 9, 10, 11</td>
</tr>
<tr>
<td>3</td>
<td>Stability of a system, input/output</td>
<td>1, 3, 5, 6, 7, 8, 9, 10, 11</td>
</tr>
<tr>
<td>4</td>
<td>Stopping of a pendulum by moving the mounting</td>
<td>1, 3, 4, 5, 8, 9</td>
</tr>
<tr>
<td>5</td>
<td>Damping of a spring-mass-system after putting it in oil</td>
<td>1, 2, 3, 4, 5, 6, 7</td>
</tr>
<tr>
<td>6</td>
<td>Matching a physical schemata and its block diagram</td>
<td>10, 11</td>
</tr>
</tbody>
</table>

A pot of soup has to be kept warm. The soup starts at a temperature of 60°C and this temperature should be kept. The product of a constant factor and the difference between the temperature of the soup and the desired temperature gives the heating of the hot plate.

How does the temperature of the soup change over time?

Figure 1: Item 1: Soup

different courses of study (mostly general engineering science, electrical engineering, mechanical engineering and chemical engineering). It is the first course on control (some of the students have had a 'Signals and Systems'-course beforehand) and it deals with classical control (1st- & 2nd-order-systems, PID-control, frequency-domain-design) and gives a small outlook on digital control at the end. The interviewed students were from different courses of study and the grade point average of the students was spread over the whole spectrum.

Items

Four items were developed before the interview period started and two more items were developed during the process. Table 1 gives an overview over the items and the interviews they were used in. All items were refined during the period of interviews. In the first few interviews, all four items (1, 3, 4, 5) were given the same attention, but the answers to Items 1 and 3 turned out to be the most interesting. Item 1 (Figure 1) was reframed to Item 2 (Figure 2) after Interview 4 in order to get more insight on the effect of different example systems. Item 1 uses a pot of soup on a hotplate as an example system, whereas a tank in an irrigation system is the example system of Item 2. The reasoning which leads to the correct answer (Figure 3), stayed essentially the same. Furthermore, Item 3 (Figure 4) was changed several times during the period the interviews were conducted. These changes are described in detail in the next section, since the way this item was developed is different than the others and worth a closer look. While the above considerations led to a focus Items 1, 2, and 3, Items 4, 5, and 6 were still used but to a lesser extent and only minor corrections in language were implemented as a result of the interviews.

A tank in an irrigation system has a constant flow of water through the outlet. The tank contains 60l of water in the beginning. This water level should be kept. The product of a constant factor and the difference between desired water level and actual water level gives the inflow into the tank.

How does the water level of the tank change over time?

Figure 2: Item 2: tank in an irrigation system
Analysis
Since the analysis is still in progress, only the part of the analysis that led to the findings covered by this paper is explained here. First, the recordings of the interviews were reviewed by the first author to get a good overview and an impression on the scope of answers the students gave. Next, the interviews were cut up into parts, each part consisting of the answers one student gave while working on one item. This allowed to compare the answers of different students regarding one item. These shorter interview passages where analysed with regard to the issues that became apparent to the first author during the interviews and while the first viewing of the recordings. Afterwards, all findings were discussed with another researcher. This was done by reviewing showcase passages and reaching consensus about the interpretation of these passages.

Results
To obtain a high relevance for the readership at REES2019, only the overarching, generalisable results are presented here, omitting the more specific control engineering issues.

Example systems
As already described in the section above, two items (see Figures 1 and 2) were identical except the example system used to illustrate the items (isomorphic questions, Smith et al., 2009). This led to insights into the role of example systems when posing a question.

First of all, the students seemed to intuitively understand the heating of a soup better than the irrigation system in these items despite asking for the same reasoning from a control theory point of view. One likely reason for this is that a pot of food on a hotplate is a more everyday setting than a tank in an irrigation system. When answering the soup example, most of the students used qualitative reasoning by themselves and more or less arrived at a sound conclusion. With the irrigation system, some students were trying to use formulas despite the fact that it is a qualitative question and the only equation expressed in the task describes only one part of the system making it impossible to answer the item by only using this equation. It seems that the students fall back on formulas (even when they just describe parts of the system in question) if they do not intuitively understand the example system. Students that were given both items in one interview (one at the beginning and the other one at the end of the interview) always saw the similarities between the items and often concluded that the answer should be the same.

The usage of example systems that are understood intuitively seems to foster thinking qualitatively about a problem and therefore leads to the measurement of the conceptual knowledge about the control concept in question. If the example system is not understood intuitively the students tend to make guesses based on the familiar looking information (in this case the one equation they could get out of the item description), which makes it hard to interpret the answers. An item invoking such guessing is not very suitable for a concept inventory, since it just measures how good the guessing strategy of the student is.
**Item development during the interview process**

This section gives an example on how the development of an item can be done in the process of interviewing students. The preferred way to develop items is to have items at a level ready for use in a concept inventory before the interviews and then just use the interviews to mainly test the language and the understanding of the items and to find response options in student language (Adams and Wieman, 2011). If, for whatever reason, this is not possible, one may start to develop an item by asking very bluntly about a concept as the evolution of item 3 (Figure 4) shows.

The item started out rather short and evolved (Figure 4) along the interviews. It was clear that stability is an important concept, but designing an item about stability that does not trigger a memorised definition or the application of an algorithm proved to be difficult. Therefore, a rather general task was used in the first interviews to generate further input from the students as starting points for an item concerning stability. In the end, the focus of the item changed slightly from targeting the concept of stability directly to targeting the input and output behaviour of a system. This is desirable, since asking directly for a concept often leads to the reproduction of textbook answers, which makes it hard to differentiate between memorisation and conceptual understanding. The answers to the first version (Figure 4a) showed that the students often only took the output of a system into account when thinking about stability. This led to the second version (Figure 4b) which explicitly took the input into account by giving an input in the task and asking for an output that should make it possible to say that the system is stable. The students did not really seem to understand what the item was asking for and often started guessing answers, which may very well be the result of the logically rather complicated structure of the question. This led to the third version (Figure 4c), which tried to invoke a misconception (stability at a certain frequency means stability of the system) which was assumed to be a misconception after the previous interviews. It also avoided to trigger the students by mentioning stability. The question posed was too broad for students to recognise that the desired answer is about stability. Most of them just read the obvious properties off of the two graphs (gain and phase shift). The fourth version (Figure 4d) is the compromise between not triggering by mentioning stability, but also giving some sense of direction. The different statements did prompt the students to give longer and richer answers. The formulations and selection of the statements still need refinement. This shows the downside of starting with such a blunt first version, one needs more interviews to arrive at an item that is ready for classroom testing in a preliminary concept inventory.

Overall, it is possible to start with bluntly asking about a concept and still end up with one or several good items, but more interviews are needed compared to starting with a sophisticated item in the beginning. Therefore, while Adams and Wieman (2011) recommend starting the interview process with a well developed item in place, our example suggests that developing the item through a sequence of interviews is also a possibility. Since preparing, conducting and analysing interviews takes a lot of time, it is better to come up with a good item right from the start, but it is not an absolute necessity.

**Patterns of incorrect reasoning**

The interviews showed some recurring patterns in wrong reasoning. The two main ones are described in this section.

All students predicted an oscillating behaviour at some point while answering Items 1 and 2, despite the fact that the example systems are in principle not able to oscillate. Such a fundamental misclassification becomes plausible as follows: Most students showed in some way that they are constructing the response of a feedback system by thinking in consecutive steps and then inferring a chronological order, not taking into account that feedback and input all happen simultaneously. In the case of the soup system, they do not only see the causal link (The heating is turned on because the soup is colder) but also a temporal sequence (The heating is turned on after the soup got colder). This thinking of a delayed reaction of the feedback can lead to the answer with an oscillating response.
Describe an unstable system.

(a) 1st version of item 3

The following input is given to a system. How should the response of the system be so that you can conclude that the system is stable?

![Graph](image)

(b) 2nd version of item 3

A system gives the shown output when exited with the shown input. What can be said about the system?

![Diagram](image)

(c) 3rd version of item 3

A system gives the shown output when exited with the shown input.

![Diagram](image)

Evaluate the following statements:
1. The system is a mechanical system.
2. It can not be said whether the system is stable.
3. The system is under feedback control.
4. It is a second-order system.

(d) 4th version of item 3

Figure 4: Evolution of item 3
Another error that almost all students answering Item 1 made is to assume that heating implies an increase in soup temperature. The same is true for Item 2 (An inflow always means a rising water level). They forget to take into account that there is also a process (the dissipation or the outflow) that causes a decrease in temperature/water level. They do this despite displaying knowledge of the dissipation/the outflow in other parts of the interview. They seem to have problems to keep all effects in mind that influence a quantity, despite mentioning them at other times. It seems to be hard for them to keep the whole system and all its workings in mind at the same time.

These two patterns of incorrect thinking are not only relevant in control engineering. For example, in electric circuits, physical quantities depend on each other, but can often be assumed to change simultaneously. Several different quantities affecting the same quantity are also common in engineering, e.g. different forces acting on an object affecting its motion (Newton’s second law) or different flows of heat affecting the temperature of an object (first law of thermodynamics). As has been observed, these patterns of incorrect thinking do not only negatively affect the proficiency in control engineering, but also hinder understanding in other engineering domains (Kautz, 2014).

Summary and conclusion
In this study, first drafts of items for the CECI were evaluated by means of student interviews. This yielded insights into student understanding, the process of developing items along with the interviews, and the role of example systems.

The interviews showed that they do not only function as a last assessment of items before a classroom test but can also be a source of inspiration for the development of items. Furthermore, it becomes apparent that the choice of example system seems to play a vital role in invoking qualitative reasoning. An example system that was not intuitively understood made the students in the interviews fall back to routines they already knew and seemed to stifle their qualitative reasoning. This is not desirable for items in a concept inventory since this qualitative reasoning shows conceptual understanding. Finally, insights on student understanding were gained by observing recurring patterns of incorrect reasoning. Two interesting patterns were observable. First, students often inferred a temporal order from a logical dependency. Second, they often did not take all factors that influence a certain quantity into account despite displaying that they know about all factors. These patterns are relevant to many engineering domains.

The next steps in the development of the CECI are drafting and testing further items, finishing the process of determining the concepts that should be covered by the CECI and looking further into the example systems and what makes them work and what not. If you are interested in the project, have ideas or insights that might help the project, or want to take part in it, please contact the first author.

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References


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The Smart Engineering Curriculum

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Abstract: The increasing complexity entailed in training engineers for the Industry 4.0 workplace requires an approach beyond simply cramming more into the curriculum. The purpose of this paper is to problematise the relationship between layers of engineering that constitute the multidisciplinary systems which require contextualised and responsive engagement with data. Using a number of social realist analytical instruments, the forms of knowledge and related practices at different levels within the ‘smart engineering’ curriculum are interrogated and subsequently illustrated so as to guide pedagogic decisions. The intention of the research is primarily to enable students to effectively develop 1) integrated systems-level thinking, and 2) appropriate, interpretative data processing skills. There is a symbiotic and analogical relationship between the design of a curricular framework for the ‘smart engineer’ and the collaborative, interdisciplinary research approach: drawing on multiple perspectives and approaches from the hard and soft sciences enables a more informed educational design process.

KEYWORDS: systems engineering; curriculum design; Legitimation Code Theory

Introduction

A widespread complaint from employers is graduate inability to apply knowledge (Griesel & Parker, 2009) acquired during their formal education, and their ‘lack of technical skills’ (manpowergroup.com, 2015). Attempts to introduce more practical technical elements into engineering curricula by way of project-based learning and traditional technical capstone projects are usually reported as successful in smaller-scale, well-resourced environments. For educators in large class contexts, such as in South Africa – the site of this research project – the challenges are more daunting. Of particular concern is the fact that in attempting to equip students to meet the demands of rapidly evolving technology- and information-driven sectors, the reality is that any technology introduced into the curriculum is likely to be redundant by the time the student graduates (Felder, 2012). The national drive to produce graduates to meet scarce skills demands and the Higher Education (HE) mandate to increase Science, Technology, Engineering and Mathematics (STEM) graduates have led to several curriculum redesign and renewal initiatives (as well as revised pedagogic strategies) in an attempt to produce the problem-solving professionals urgently needed to address national Sustainable Development Goals. One such initiative is the conceptual design of a theoretically-informed framework for the 21st century ‘smart engineer’ in the ‘digital ecology’ (WEF, 2016a) that characterises Industry 4.0.

“We are at the beginning of a global transformation that is characterized by the convergence of digital, physical, and biological technologies in ways that are changing both the world around us and our very idea of what it means to be human. The changes are historic in terms of their size, speed, and scope” (WEF, 2016b).
With the emergence of the mobile devices that form part of the internet of things (IoT) in a massive system of interconnected devices (Things), multiple new challenges face engineers who have hitherto been exposed to a silo-structured curriculum, and siloed way of thinking. Engineering students in our context tend to be taught from the ground up, starting with core physical fundamentals (physics, chemistry, mathematics) with the objective of working towards a toolbox of disparate knowledge areas culminating in the fourth-year capstone project which is intended to integrate the preceding knowledge and is used to assess the student’s ability to perform industry-mimicking tasks. The ‘toolbox’ approach is also evident in the divisions between the different branches of engineering. Categorisations of what have come to be called engineering ‘disciplines’ routinely ignore or avoid a more conceptual approach, listing fields such as software engineering, mechanical engineering, biomedical engineering and systems engineering side by side as though they were comparable. In South Africa there is little differentiation in curricula with regard to scope, scale and nature of work across engineering sectors, and the most common curricular approach for capstone projects is the Conceive-Design-Implement-Operate (CDIO) sequence (Crawley, 2001), which is appropriate to small-scale Research and Development environments. The majority of graduates, however, do not find employment in such niche areas – which operate with a fundamentally different organisational logic (Wolff, 2017); rather, employment is more common in medium to large-scale sectors where very little design (in the CDIO sense) takes place. The industry complaints with regard to ‘soft skills’ (Cappelli, 2014) attest to the lack of ability to work in more complex organisational structures, with the concomitant communication, teamwork and social practices.

The categorisation of engineering sectors does not take into account that software, computer and systems engineering, for example, underpin and affect all sectors, including those professions beyond engineering. The increasing interdisciplinarity emerging in such areas as mechatronics and industrial engineering, as well as the Industry 4.0 paradigm suggests that we have outgrown the silos and need to rethink the training of our engineers. The highlighting of graduate lack of technical and ‘soft’ skills, we suggest, bears testimony to our inability as educators to enable students to engage in relational, part-whole thinking. The changing technological landscape poses “major challenges requiring proactive adaptation by corporations, governments, societies and individuals” (WEF, 2016b). This is where the future SMART engineer enters the picture.

The easiest analogy to illustrate the 21st century trajectory in engineering is that of a coder versus a software systems engineer. A coder is the detailed implementation agent, with the systems engineer ensuring that everything is appropriately connected and working together. These two functions require significantly different mindsets and practices. With smart systems, the engineer cannot afford to be bogged down by the detail. The engineer has to be exposed to macro ways of thinking from the outset, albeit in parallel with certain fundamentals that require micro, detailed approaches. The systems engineer essentially integrates systems that span multiple disciplines. These disciplines are not limited to engineering though, and are very reliant on the so-called “soft skills” such as ethics, environmental impacts, societal and economic impacts. Although specified by engineering qualification standards as important attributes of an engineer in any field, these attributes take on an entirely different significance in the context of the pervasive and massive scale at which smart systems will be employed in the internet of things and Industry 4.0, where machines and humans co-exist in ways never seen before, “affecting labor markets … as well as social value systems and ethical frameworks” (WEF, 2016b). The scale and dynamic pace of technology imply major environmental impact, with billions of devices 1) disposed of annually, and 2) using power and emitting interference.

The purpose of this paper is to present a conceptual framework which can illuminate the complexity facing the Smart Engineer (SE) and to suggest a curricular and pedagogic approach that may enable holistic, contextualised engagement with data generated by multidisciplinary systems in complex socio-technical contexts, with a view to the effective
development of 1) integrated systems-level thinking and 2) appropriate, interpretative data processing skills at different levels of the system.

Conceptual Framework

Knowledge structures in 21st century engineering

The theoretical focus of this paper is a rigorous conceptualisation of the nature of knowledge and its concomitant practices underpinning the structure of a SE curriculum with a view to improving engineering programmes designed to meet the needs of increasingly complex 21st century socio-technical environments. It is our position that current programmes are inadequately conceptualised from the perspective of the required knowledge practices in technology-driven sectors. Engineering curricula are framed by three international engineering accords which stipulate mathematical, natural and engineering sciences as the core disciplines. The structure of these disciplines (and the implications for learning) can be described using social realist theory.

Basil Bernstein (2000) described knowledge as kinds of ‘codes’ – invisible structures based on rules established in different fields of practice. Our task, as educators is to understand how these codes arise, so as to make them explicit for the purpose of ‘learning the rules of the game’. One way in which we do this is to ‘frame’ the learning experience. ‘Framing’ is about what goes into the curriculum, in what order, at what pace, and against what criteria. Framing is also about ‘who’ controls the ‘frame’. Bernstein differentiates between three kinds of formal knowledge structures, each of which needs to be framed differently for effective learning. Hierarchical knowledge structures, represented by the natural and physical sciences, attempt “to create very general propositions and theories, which integrate knowledge at lower levels” (Bernstein, 2000). This means that new theories or concepts subsume earlier ones, creating a visible sequence over time. We see this in the traditional school science curriculum, where we start with matter then motion then energy and so on. Learning this kind of knowledge requires strong sequencing and the grasp of each preceding concept, and usually manifests as ‘teacher-centred’ pedagogy (Winberg, et al., 2018). In other words, hierarchical knowledge structures are acquired more effectively with the guidance of a ‘knowledgeable other’ who tightly ‘frames’ the learning experience, deciding on the content, order and criteria required to master the knowledge.

Horizontal knowledge structures, on the other hand, “consist of a series of specialised languages with specialised modes of interrogation and criteria for the construction and circulation of texts” (Bernstein, 2000). We have ‘strong’ horizontal knowledge structures and weak ones. Both types simply have different ‘languages’ of the same type of knowledge, each with its own rules. Where the rules for each language of the same type (or family) are ‘strong’, we refer to them demonstrating a ‘strong grammar’. Any mathematical theorem is a good example of a strong ‘conceputal syntax’ which is easily empirically identifiable. In the case of horizontal knowledge structures, ‘masses of particulars’ (Muller, 2009) need to be learnt independently, not necessarily sequentially, and usually in specific contexts. This means more time is required for the acquisition of this kind of knowledge. It also means the framing over what must be learned in what order can be weaker, with the student taking more control.

Horizontal knowledge structures with ‘weak grammars’ are those where the “capacity of a theory to stably identify empirical correlates” is weaker (Young & Muller, 2007). This is evident in forms of knowledge which routinely borrow concepts and terms from other fields, and which see rapid obsolescence. Human languages are a good example, as are information communication technologies. Bernstein talks about the ‘regionalisation’ of knowledge (2000), evident in such fields as engineering, where one sees the weakening of boundaries between the disciplinary bases, such as in the case of ICTs - a ‘region’ which is at the heart of 21st century multidisciplinary engineering practice. The primary disciplines underpinning ICTs are ‘logic’ and mathematics, both of which are horizontally structured.
However, the disciplinary ‘logic’ implied in engineering control systems today has become increasingly complex, with an ever-weakening ‘grammar’. Acquiring knowledge with a ‘weak’ horizontal structure, such as ‘logic programming’, means not only learning each new relevant ‘language’ as it is created or required, but staying abreast of structural and even conceptual changes to the same ‘language’, as it is the users who drive change in the field of application or social context. In this case, framing can be very weak, meaning the student controls the sequence, and needs opportunities to experience multiple types and application contexts.

**Multidisciplinarity in the curriculum**

Multidisciplinary engineering, such as in SE, requires the iterative navigation of these different disciplines, each of which implies a significantly different ‘code’ or way of thinking. Figure 1 captures the broad foundational systems of a multidisciplinary engineering curriculum with the associated dominant knowledge structural forms. There is an implied hierarchy as one moves from the physical systems to the ‘invisible’ control layer.

Another useful Bernsteinian concept in relation to the curriculum is that of classification. If the core disciplines are characterised by organising principles which can be clearly differentiated, then these disciplines are regarded as ‘bounded’, or insulated from other disciplines.

Strongly classified ‘singles’ (such as physics and mathematics) lend themselves to a collection-type curriculum, which sees the “organisation, transmission and evaluation of knowledge as bound up with patterns of authority and control” (Bernstein, 1977). This is precisely the silo curriculum structure we still see in traditional engineering curricula (UNESCO, 2010). The emergence in 20th century education of ‘regions’ such as Medicine and Engineering weakened the classification of the pure disciplines. The boundaries between disciplines reflect social power relations. When boundaries are blurred, disciplines or their agents risk losing their specialisation and status - the social order is threatened. This may well be why there is such resistance to altering the silo curriculum structure.

A further challenge for systems engineering educators is that effective ‘systems’ are built on a productive, causal relationship between mathematics and logic (characterised as having strong and weak ‘grammars’ respectively). In essence, mathematics is the science of patterns. The kind of mathematical thinking implied in SE goes well beyond the confines of Calculus (the backbone of traditional engineering) or statistics. The SE needs to work in all mathematical branches, given the topological complexity of IoT systems. The reality is that the engineering ‘regions’ of the 21st century blur multiple boundaries. For a region to survive, there must be a ‘relational idea’ (Bernstein, 1975) and strong lateral relations – in other words, inter-/multi-disciplinary collaboration, and inter-/ multidisciplinary forms of thinking. What exactly does this form of thinking look like?

**Analytical Tools**

Legitimation Code Theory (LCT) (Maton, 2014) offers a dimension which can help to illustrate what multidisciplinary thinking looks like. The Specialisation Epistemic Plane (figure 2 - left) illustrates the relationship between a phenomenon and its approaches, the what and how of any knowledge practice. The what and how axes differentiate between how strongly ‘bounded’ a phenomenon is (‘classified’ in the Bernsteinian sense) and how fixed the approach to that phenomenon is (‘framing’ in the Bernsteinian sense). The physical sciences are strongly bounded phenomena with fixed approaches. This means that one needs purist...
insight to effectively grasp these concepts. Where the phenomenon is not important, rather the rules/strict methods are, we talk of needing doctrinal insight, such as mathematical functions or syntax rules. One needs situational insight when there are open-ended methods for a clearly defined phenomenon. When the phenomenon and approach are weaker, one talks of having ‘no insight’ or the issue is not about knowledge, but knowers in the system.

Figure 2. Knowledge structures on the epistemic plane (based on Maton, 2014 p.177)

The Epistemic Plane (Maton, 2014) has been used in engineering problem solving research to demonstrate how practitioners navigate between different disciplines as they approach (1), analyse (2), identify the cause (3) and solve (4) a controlled electro-mechanical problem in industrial contexts (Wolff, 2017). Successful practitioners (figure 2 - right) follow different patterns, depending on context and personal ‘insight’ orientation. One of the key findings from the industrial case studies is that the greatest challenge for most new graduates is shifting from the right to the left, in other words, not being able to cope with more flexible approaches in more complex contexts. The successful systems integrators in the study start with the ‘big picture’ in the ‘situational’ quadrant, and consider multiple possibilities. They also navigate more easily to the ‘contextual’ stakeholder quadrant to understand the situation better, and draw on a range of appropriate methods (most acquired in the industrial context).

What this suggests, if one returns to the knowledge structural features, is that working on the left-hand side of the Epistemic Plane (which are precisely the ‘skills’ industry requires) entails greater flexibility and a broader range of challenges. Knowledge structures situated on the left-hand side require weaker framing, in other words more control by the student. This is precisely the ‘self-regulated’ learning required to be demonstrated in Graduate Attribute 9 of the engineering qualification standards. So, what are the implications for a SE curriculum?

The SE Curriculum

Let us consider the SE domain as consisting of multiple layers. At each level there is a relationship between the fundamental sciences and context, which has implications for decisions as to curricular and pedagogic approaches (figure 3). The physical layer (1) includes all things that can be controlled and/or measured, energy storage and harvesting, and mobility. With regards to mobility, the physical location is of special importance for this field, but included is also the dynamic physics, i.e. the way in which things that move are measured by MEMS sensors. [Despite its importance and pervasiveness in modern sensing systems, its novelty has resulted in its exclusion from traditional curricula]. The energy harvesting in this case includes power conditioning from traditional sources, although the modern trend is for distributed energy harvesting. The sensing and actuation layer represents the sensor technologies and actuation technologies. Given its tight coupling to the physical system that is controlled, it spans across the Physical domain. This layer also includes the driving circuitry, for example an H-bridge driving a stepper motor. Each of the
elements in the physical layer is not only underpinned, but dictated by physics-based (hierarchical) laws, from those governing motion and thermodynamics to Ohm’s Law. Engineers working at this level require these laws at their fingertips; in other words, they require stronger **purist insight**.

Figure 3. The SE knowledge topology

Above the sensing and actuation layers is the energy transfer and inter-component or signal transfer (2). This layer captures the method employed to convey the “sensed” quantity (e.g. sampled quantity represented as volts or communicated as serial data) and the same for actuation. This could include opto-isolated or magento-isolated sensing (e.g. signal transformers). In modern systems, this layer often also includes inter-component wireless communications, such as modbus, Zigbee, Bluetooth or WiFi. In addition, we have the transfer of energy between the energy source or storage through copper or transformer. As in the physical layer, the signal production and transfer process itself is governed predominantly by the physics of electricity/electromagnetism and classical Calculus.

However, here we see the first key transition into the interpretative space, where different statistical mathematical methods (**doctrinal insight**) can be used to analyse, extract and transform signals selectively, depending on what information the end-user (whether another machine or human) requires to be able to continue or complete a process. This marks a step into the weak horizontal knowledge structure of logic-based sciences, where the logic is dictated by the end goal and non-physics-based determinants. In other words, here the engineer is required to move iteratively between the **doctrinal** and **situational insights** (figure 4).

The computer control system (3) contains the processor and firmware, which are significantly different from historical processors and firmware architecture. The main differences relate to the locus of control, redundancy and mitigation of failure for safety and efficiency, local state...
persistence in the event of communications failure in the higher levels. A secondary effect of these strategies is the requirement for local storage and synchronisation thereof, for example storing schedules and target temperatures, in case the cloud control is unavailable - a highly likely scenario that must be accommodated. Although the intention is for these devices to be much less sophisticated than in historic systems, there is quite often the need for some local processing, both to reduce data transfer, and to enable local decision making. Again, as in the previous layer, the nature of and relationship between these devices is dependent on contrasting insights. The situation is that the firmware is not cast in stone, and upgrades have a knock-on effect on sizing and re-writability requirements on programme memory. However, the ability of the processor to compute and relay signals is governed by the laws of physics and Boolean arithmetic (purist and doctrinal insights). The question for engineering educators here becomes more complex: what level of understanding of the firmware and processing aspects of the control layer are required to enable effective fault-finding when managing ‘big data’?

The layer above the computer control system is entails getting the remote part of the system “onto the cloud” (4). This is usually done with a modem that is either on the same PCB (sometimes embedded with the controller as a system on chip), or connected with some form of local communications, such as Zigbee or modbus. The processor therefore can either go through an exchange, condenser, convertor, aggregator, etc, or directly into the gateway, which provides the wireless communications. Available technologies in this layer, commonly termed Low-Power Wide-Area Networks (LPWAN), are evolving at an exponential rate, each with their own limitations and special features. This is characteristic of weak horizontal knowledge structures, which require the constant acquisition of “masses of particulars” (Muller, 2009), and the iterative movement between situational and doctrinal insights.

Once the information is communicated from the remote device, a cloud-based plethora of systems (5) have to be in place to ensure seamless, safe, and secure system operation. The hierarchy in the software engineering block, however, is not as clearly defined, with no standardisation of components and major challenges for security (Booysen et al., 2012). The reason for this is that either the practices required are all dictated by users – in other words, knowers in the system – or there is no clarity as to the overarching purpose – in other words ‘no insight’ or no clear ‘relational idea’ (Bernstein, 2000). For complex regions to survive, there needs to be consensus as to the overarching purpose. One sees ‘no insight’ in complex systems where there are contradictory paradigms, such as for example in education which attempts to achieve social justice through forms of managerialism designed for economic competitiveness. The moment one sees references to users (‘humans’) in the system, then the knowledge practices become more complex and draw on different, competing forms of knowledge.

In the software engineering layer, the user control and admin control are different access methods from clients into the system. The user typically has access only to a basic interface in which two separate types of management can be done - the devices or assets (e.g. the device being monitored and/or controlled, typically with an “overview” view and a detailed asset-bespoke interface) and account management (e.g. billing, contact details, login details, site configuration, etc.). The administrator typically has access to all devices/assets and all user profiles. Before any users can be given access, user access control must be set up, to allow users to register, log contact details, set preferences, accept terms, and setup payment options (if applicable). These core functions are paramount, but entirely dependent on situational and knower requirements currently not even considered in engineering courses.

The reporting in these types of systems presents a layer of complexity that moves beyond ‘formal’ knowledge: there is no use reporting content that is not understood or able to be visualised and easily interpreted. This is often where software engineers struggle to make sense of the data that is at different levels of being processed and converted, and to visualise it in a human-readable format. A key limitation here is that the approach is often a doctrinal (technical) one, as opposed to the knower-orientated approach required to produce
user-friendly, visualised, and accessible information. The lack of appropriate communication skills at all levels is well reported in the literature (Cappelli, 2014). This suggests the SE student needs intimate knowledge of the physical and sensing system, all the way through to an understanding of the reporting system.

In summary, the five layers as characterised demonstrate a natural hierarchy, from traditional ‘stable’ disciplines to increasingly weaker ‘regions’. However, the dilemma in designing both an educational framework as well as the system itself lies in the design ‘direction’. Engineers follow a processor-centric development, as the processor has historically been the centre. This was mainly a top-down design when processors were central. However, with the remote access to the cloud and the shift in the loci of some fundamental control functions, the processor-centric development ends up being half top-down and half bottom-up. The requirement is now for the design to be top-down from the cloud, AND top-down from the processor, almost as two separate but equal systems. There are two major challenges in mis-directed design: If the software engineering layer design is done from a processor perspective (bottom-up into the cloud), security will be compromised, the cloud system will be very difficult to maintain, bottlenecks will occur in the cloud-remote system interface layers, systems will not be able to cater to similar solutions, as they will be developed with a “silo” mentality, rather than reusable cross-application mentality, and the wrong platforms will be chosen. The second key challenge is that software engineers used to implement what they were told by the hardware or systems engineers. Now that control lies in their domain, and their domain knowledge is key to a good design, this calls into question the required scope and depth of knowledge and associated practices in order to effectively manage such complex cloud-based systems. It is therefore a daunting task to include these in any undergraduate material, and often recent engineering graduates have very little or no knowledge of these available technologies and how they compare.

Concluding Comments and Recommendations

The theoretically-informed analysis of five layers of complexity entailed in the ‘Smart Engineering’ system demonstrates a trajectory from traditional stable science-based disciplines in the physical systems layer towards increasingly complex and competing forms of knowledge characterised by interdisciplinary ‘regions’ in the software engineering layer. This is precisely the sequence in which traditional engineering curricula are structured. However, the analysis attempted to illuminate the fractal nature of each layer, with each consisting of sub-elements and forms of knowledge of the preceding layer. As the complexity increases, this calls into question just how much one can feasibly squeeze into an already overfull curriculum. We suggest that this ‘bottom-up’ sequence does not allow for the development of the ‘top-down’ view of the SE system. The transition in mathematical sciences through the layers as well as the dominance of horizontally structured, logic-based knowledge suggests the need for a curricular and pedagogic approach that allows for iterative and cyclical movement across different forms of knowledge and ways of thinking (insights) that build towards the overarching relational idea. We recommend that:

1) it is necessary for educators to reconceptualise what it means to develop systems thinking abilities, and suggest that a more explicitly relational approach to the foundation disciplines may elicit an understanding of ‘the science of patterns’ – which is how mathematics itself is described (Schoenfeld, 2009);

2) the pedagogic approach needs to shift towards a more student-centred and self-regulated learning ethic, given the shift from hierarchical knowledge structures requiring purist insight towards increasingly weaker horizontal knowledge structures requiring knower insight.

Finally, there is a symbiotic and analogical relationship between the design of a curricular framework for the ‘smart engineer’ and the collaborative, interdisciplinary research approach: drawing on multiple perspectives and approaches from the hard and soft sciences enables a more informed educational design process.
References


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Promoting adoption of active learning and use of strategies to reduce student resistance to active learning

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Abstract: Our research has identified strategies instructors can use to reduce student resistance to active learning, and we are developing a workshop intervention to change instructors' motivation and behaviour related to adoption of active learning and of these strategies. We are using a randomized control trial to assess the impact of the workshop on instructors' value, self-efficacy, and actual adoption of both active learning and the strategies to reduce resistance. In this paper, we describe our processes for recruiting workshop participants and for developing an instructor survey to assess the impact of the workshop.

Keywords
Active learning, faculty development, motivation, student resistance

Introduction
There is convincing evidence about the positive benefits of implementing active learning in Science, Technology, Engineering, and Math (STEM) classrooms, both in the United States and internationally. Active learning – which we define as students doing anything in class to learn material, other than listening to the instructor and taking notes – has been shown to improve student learning, engagement, and interest in STEM (Freeman et al., 2014; Koch, Dirsch-Weigand, Awolin, Pinkelman, & Hampe, 2017; Lucke, Dunn, & Christie, 2017; Prince, 2004; Rodriguez et al., 2015; Seymour & Hewitt, 1997; Smith, Sheppard, Johnson, & Johnson, 2005; Yusof, Tasir, Harun, & Helmi, 2005), promote success for a diverse student body (Seymour & Hewitt, 1997; Tobias, 1990), and increase the retention rate of students in STEM programs (Blackburn & Lawrence, 1995; Freeman et al., 2014). Yet, in spite of the overwhelming evidence of the efficacy of active learning, adoption of active learning in undergraduate STEM classrooms has been limited (Dancy, Henderson, & Turpen, 2016; Gradinscak, 2011; Jamieson & Lohmann, 2012; Stains et al., 2018). Thus, one key challenge now is to increase the use of active learning in STEM by addressing barriers to adoption.

Instructors cite multiple barriers that inhibit their adoption of active learning (e.g., Finelli, Daly, & Richardson, 2014; Henderson & Dancy, 2007; Seidel & Tanner, 2013), including concerns about: (a) the efficacy of active learning; (b) the preparation time required to implement it; (c) class time and the instructor’s ability to cover the syllabus; and (d) student resistance. While instructor concerns about the efficacy of active learning are a legitimate barrier, this efficacy has been exhaustively documented, as we outlined above; thus, it requires little additional research. Similarly, concerns about both preparation and class time have been addressed
convincingly in the literature (Felder, 1992, 1994; Felder & Brent, 2009). However, student resistance (i.e., any negative student response to active learning that would discourage an instructor from using that activity, including refusing to participate, distracting others, or giving low course evaluations) has not been the subject of significant research. We therefore focus on student resistance as the most actionable barrier to the adoption of active learning.

Through our previous research involving classroom observations, instructor interviews, and student surveys in 19 diverse STEM courses across the United States, we found that students most often responded positively when their instructors asked them to engage in active learning (DeMonbrun et al., 2017). Student resistance to active learning was not common, and when it did happen, it generally manifested as passive behaviour rather than open, confrontational behaviour (Nguyen et al., 2017).

Our research further identified several promising strategies that can reduce student resistance to active learning. Specifically, instructor’s use of explanation strategies to introduce an activity and describe its purpose, facilitation strategies to promote engagement and keep the activity running smoothly, and planning & feedback strategies to plan the activity, assess its success, and use feedback to improve it are related to greater student participation, less distraction, and higher course evaluations (Finelli et al., 2018; Nguyen et al., 2017; Tharayil et al., 2018).

Now, armed with these strategies to reduce resistance, we aim to promote adoption of active learning among STEM instructors through a workshop that will both address the benefits of active learning and help instructors use these strategies to reduce resistance. Our workshop focuses on changing instructors’ behaviour by increasing their motivation (i.e., value and self-efficacy) for using both active learning and the strategies to reduce resistance. Accordingly, we ground the design of our workshop in the Expectancy Value Theory of motivation (Eccles & Wigfield, 2002) as well as in prior research about active learning (e.g., Prince, 2004), student resistance to active learning (DeMonbrun et al., 2017; Finelli et al., 2018), and faculty professional development (Felder, Brent, & Prince, 2011).

STEM-focused faculty professional development programs, including single- or multi-day teaching workshops like ours, have become increasingly common across the United States (Jamieson & Lohmann, 2012; Felder, Brent, & Prince, 2011). Such programs have been shown to affect instructors’ behaviour (Condon, Iverson, Manduca, Rutz, Willett, & Huber, 2015; Gibbs & Coffey, 2004) and to be an efficient way for instructors to improve teaching (Felder, Brent, & Prince, 2011). Thus, we expect that our workshop will influence instructors’ use of active learning and the strategies to reduce resistance.

We will hold identical workshops for instructors who teach introductory STEM courses in three separate regions of the United States: the Midwest, South, and West, and we will conduct our project as a Randomized Control Trial (RCT) by randomly splitting participants into an intervention group and a comparison group. Instructors assigned to the intervention group will participate in the workshop during Year 1, while instructors assigned to the comparison group will participate during Year 2. Thus, by the end of the two-year project, instructors in both groups will have participated in the workshop. For both groups, we will assess the instructors’ motivation for using both active learning and the strategies to reduce resistance and their actual behaviour by collecting and analysing data from multiple sources, including classroom observations, instructor surveys, and student surveys. Triangulating and comparing these data for the intervention and comparison groups both before and after the workshop will allow us to study the impact of the workshop.

For this Work-in-Progress paper, we describe two components of the larger project: participant recruitment and our instructor survey to assess the impact of the workshop on instructors’ motivation and behaviour. Future publications will more fully address the design of our workshop and other data collection instruments, and we will broadly share our research findings as they become available.
Methods

Participants

Several design decisions influence our process for recruiting workshop participants. These include how we: (1) define introductory STEM courses, (2) identify eligible STEM instructors, and (3) form the intervention and comparison groups for our RCT.

1. Introductory STEM courses

There has been little research about course-related factors that might influence student resistance to active learning (e.g., the discipline of the course, whether the course is required or elective, whether the course comprises introductory or advanced material). Thus, we focus on promoting the use of active learning and strategies to reduce resistance in introductory STEM courses in the United States to reduce variability in classroom context, and we begin by clarifying a working definition of introductory STEM courses.

A number of possible definitions for STEM have been discussed in the literature (Koonce et al., 2011), and these definitions differ primarily in two ways: how broadly the term “STEM” is interpreted, and whether or not the social sciences and healthcare are included. We adopt the convention recommended by the United States Government Accountability Office (2014) by including core STEM fields in our definition. Under this categorization scheme (Figure 1), our definition of STEM includes engineering, life sciences, physical sciences, computer and information technology, and mathematics and statistics. Further, we define introductory STEM courses as first- or second-year courses in one of the core STEM fields that are both (1) primarily targeted to students within the first two years of a nominal four-year degree program or offered by a two-year institution and (2) offered by a STEM department or judged to have course content that falls substantially within one of the STEM fields.

![Figure 1. Definition of STEM fields (adapted from United States Government Accountability Office (2014))](image)

2. Eligible STEM instructors

Our systematic process for recruiting instructors who teach introductory STEM courses involves identifying eligible college and universities in the United States, compiling contact information for relevant administrators and instructors at those institutions, and then inviting workshop participants. To be eligible for our project, an institution must satisfy three requirements. First, because we will conduct in-class observations of our participants, we restrict our research to institutions within a 150-mile driving distance of the three regional workshop locations (Ann Arbor, Michigan in the Midwest; Austin, Texas in the South; and Eugene, Oregon in the West). Second, because it involves instructors teaching introductory
STEM courses, we restrict our research to institutions having a STEM department, program, major, or (if none of those exist) introductory course. And third, we restrict our research to public or not-for-profit private institutions and to two- or four-year institutions.

To identify eligible institutions, we merged data from the CollegeNavigator online database (National Center for Education Statistics, 2018) and the Integrated Postsecondary Education Data System (National Center for Education Statistics, 2015), compiled the driving distance for all institutions within 150 miles from the closest regional workshop location (using zip code), and determined whether those institutions offered a STEM degree. We also recorded additional information for each institution including Carnegie Classification®, size, and setting, by consulting the Carnegie Classifications of Institutions of Higher Education® database (Indiana University Center for Postsecondary Research, 2016).

Next, we reviewed each eligible institution’s website to collect contact information of either a relevant administrator who would forward our email invitation to workshop candidates or the candidates themselves. Specifically, for every STEM department/program/degree at the eligible institution, we first looked to identify contact information of a relevant administrator (STEM department chairperson, unit head, or key faculty contact) on the institution’s website. If that information was not available or if the STEM program did not have a relevant administrator, we collected contact information for workshop candidates as follows:

- If less than ten instructors were listed, we added contact information for all instructors,
- If either ten or more instructors were listed or none were listed, we included the contact information for the Dean,
- If ten or more instructors were listed and the Dean was not listed, we included contact information for ten instructors selected randomly from the institutions’ webpage, and
- If none of this information was available, then the institution was dropped from our list.

Now, after having compiled contact information, we will recruit participants by sending targeted email invitations to individuals on each recruitment list approximately three months before each regional workshop. Our recruitment emails either will either ask relevant administrators to forward the invitation to instructors in their program who teach introductory STEM courses or will personally invite instructors to participate in the workshop (and encourage them to forward the message to their colleagues). The emails will further describe that, to be eligible for the project, instructors must plan to teach an introductory STEM course during both Years 1 and 2 of the project, and they must be available to attend the workshop during both years.

3. Intervention and comparison groups

Instructors who are interested in participating in our project will complete a baseline questionnaire with items about instructor demographics, background characteristics, prior experiences with active learning, and a target class session in which the instructor plans to adopt active learning (e.g., approximate student enrolment, programs or majors that require the course, class level of students, etc.). We will use data from the baseline questionnaire in two ways. First, we will screen out instructors who do not satisfy the inclusion criteria; i.e., those who do not expect to teach an introductory STEM course during both Years 1 and 2 and those who are unable to attend the workshop on both pre-scheduled workshop dates. Second, we will use data from the instructors who do satisfy our inclusion criteria to create two equivalent groups (Intervention and Comparison) for each of the three regions, asking instructors in the intervention group to participate in the workshop during Year 1, while asking instructors in the Comparison group to delay their participation until Year 2. We will utilize block randomized assignment to ensure that both groups have equal representation of instructors having various characteristics (e.g., teaching at two- and four-year institutions), allowing us to conduct our project as an RCT.

In the medical field, RCTs are considered the gold standard for establishing the efficacy of a clinical intervention, since they allow for the study of a treatment when it is not possible to
control for or isolate all possible relevant variables. Owing to the success of RCTs in clinical research, many educational policy makers and researchers have pushed for RCTs in educational contexts, arguing that educational policy should be shaped by the available scientific evidence regarding the efficacy of educational interventions. The efficacy of RCTs in educational research, though, is controversial. Research reports from the National Academy of Education (e.g., Singer, Braun, & Chudowsky, 2018) do feature RCTs as the gold standard for determining causality of an educational intervention, but others agree that applying RCTs to educational contexts can be problematic (e.g., Sullivan, 2011). It is often not possible to control for the many sources of error that may occur in real-world educational settings, such as differences in personal characteristics of participants, differences in the intensity of the intervention, and institutional inequities, and the random assignment of individuals to comparison groups can potentially harm participants in the comparison group if valuable treatment is withheld from them (Cohen, Manion, & Morrison, 2018; Sullivan, 2011).

We acknowledge that issues related to institutional inequities may present a limitation to our research. We further acknowledge that we will be unable to control many of the factors that might be important to our study, such as the teaching experience of each instructor, the instructor’s prior use of and success with active learning, the content of the course, and the culture of the institution. However, using a block randomized assignment process ensures that these differences between participants will occur at random.

We are confident that the RCT will not harm participants in either the intervention or comparison group. Considerable prior research has demonstrated the efficacy of both active learning and the strategies to reduce student resistance, and we have extensive faculty professional development and workshop delivery experience, so there is no likely harm to the intervention group from participating in our workshop. Further, the comparison group will have delayed participation in the workshop (they will participate during the second year); so since the workshop will not be withheld from them, there is no likely harm to the comparison group. The institutional review boards at the three regional workshop sites have each approved these research plans.

Instructor survey

We aim to explore the impact of our workshop on instructors’ motivation (i.e., value and self-efficacy) and behaviour related to adoption of active learning and the strategies to reduce student resistance to active learning. We will collect data for both the intervention and comparison groups from three sources: instructor surveys, student surveys, and classroom observations, all administered at multiple times during both Years 1 and 2. Table 1 shows the approximate timeline for data collection. Here, we describe our instructor survey.

<table>
<thead>
<tr>
<th>Table 1. Data collection timeline for intervention (INT) and comparison (COMP) group</th>
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<tbody>
<tr>
<td>Year 1</td>
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<tr>
<td></td>
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<tr>
<td>Before workshop (June 2019)</td>
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<tr>
<td>After workshop (June 2019)</td>
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<tr>
<td>During the semester (Oct 2019)</td>
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<tr>
<td>Year 2</td>
</tr>
<tr>
<td>Before workshop (June 2020)</td>
</tr>
<tr>
<td>After workshop (June 2020)</td>
</tr>
<tr>
<td>During the semester (Oct 2020)</td>
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</tbody>
</table>

We will administer the instructor survey two times each year to all participants in both the intervention and comparison groups: the day before the workshop and once during the following semester. Workshop participants will also complete the instructor survey immediately after the workshop. Participants will identify a target class session, approximately half way into the semester in which they plan to use active learning. We will
administer the instructor survey on the day of the target class session, allowing instructors to respond to items about that specific class period.

Drawing on our team’s prior research (DeMonbrun et al., 2017), our instructor survey includes a five-item “active learning” scale and a 17-item “strategies to reduce student resistance” scale. We previously demonstrated both of these scales to be valid and reliable measures of student perceptions of instructor behaviour (Nguyen et al., 2016). Table 2 includes the items for both scales. When we administer the instructor survey before and after the workshop, we will use two motivational constructs, value and self-efficacy (Bandura, 2006; Eccles & Wigfield, 2002), to measure instructor motivation for using both active learning and the strategies to reduce student resistance. To assess value, respondents will indicate how valuable they believe it is to do each of the 22 items on the two scales, and to assess self-efficacy, respondents indicate how confident they are in their ability to do each item. To assess behaviour when we administer the instructor survey during the semester, respondents will indicate how frequently they did each item during the target class session.

<table>
<thead>
<tr>
<th>Table 2. Scales for active learning and strategies to reduce student resistance</th>
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<tr>
<td><strong>Active learning</strong></td>
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<tr>
<td>1. Ask everyone in class to do a course-related activity other than watching, listening, or taking notes</td>
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<tr>
<td>2. Give students a minute or two to think about an instructor-posed question before letting someone answer the question or calling on one or more students to answer it</td>
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<tr>
<td>3. Ask students to discuss concepts with classmates during class</td>
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<tr>
<td>4. Ask students to solve problems in a group during class</td>
</tr>
<tr>
<td>5. Ask students to solve problems individually during class</td>
</tr>
<tr>
<td><strong>Strategies to reduce student resistance</strong></td>
</tr>
<tr>
<td>1. Plan the activity based on how well a similar activity worked in the past</td>
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<td>2. Structure the activity with small steps that students can accomplish confidently</td>
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<tr>
<td>3. Specifically design the activity to maximize student engagement</td>
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<tr>
<td>4. Design the activity to connect with the rest of the class period or lesson plan</td>
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<tr>
<td>5. Use feedback from students to design the activity</td>
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<tr>
<td>6. Following the activity, think about what did and did not work</td>
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<tr>
<td>7. Explain what students are expected to do for the activity</td>
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<tr>
<td>8. Explain the purpose of the activity</td>
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<tr>
<td>9. Discuss how the activity relates to student learning</td>
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<tr>
<td>10. Describe how the activity relates to graded assignments</td>
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<tr>
<td>11. Solicit feedback from students about how the activity went</td>
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<tr>
<td>12. Walk around the room to assist students with the activity if needed</td>
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<tr>
<td>13. Encourage students to engage with the activity through your demeanour, body language, or interactions with students</td>
</tr>
<tr>
<td>14. Approach students who are not participating in the activity if you see them</td>
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<tr>
<td>15. During the activity, invite students to ask questions about it</td>
</tr>
<tr>
<td>16. Give students points based on their participation in the activity</td>
</tr>
<tr>
<td>17. Lead a debrief or report-out as a whole class following the activity</td>
</tr>
</tbody>
</table>

We are currently pilot testing the items on our instructor survey by conducting a scale validation study on a sample of approximately 500 STEM instructors in the United States. By the time of our REES presentation, we will have conducted a confirmatory factor analysis utilizing structural equation modeling for each scale, and we will be able to report scores of convergent validity, structural validity, and reliability of responses to the measures.

**Other Project Components**

1. **Workshop intervention**

We are piloting our workshop intervention in Summer 2019. The workshop has two major segments, the first of which provides an introduction to active learning for STEM instructors. The workshop facilitators will begin by defining active learning and presenting research about its effectiveness. Then, after collecting and addressing instructors’ concerns about using
active learning strategies, the facilitators will provide participants with both additional
guidance for using active learning and with opportunities to practice it and get feedback. The
second segment of the workshop will focus on strategies to reduce student resistance to
active learning. The facilitators will present research showing positive correlations between
use of three types of strategies (explanation, facilitation, and planning/feedback) and lower
measures of student resistance, and then they will share practical examples of using the
strategies with participants. Finally, participants will have opportunities to practice using the
strategies and get feedback. By the end of the workshop, participants will develop an action
plan to successfully adopt active learning and reduce student resistance.

2. Other instruments

Besides the instructor survey, our overall project involves data collection from two other
sources: student surveys and classroom observations. The student survey will be
administered in the middle of the semester, concurrent with the instructor survey, and it will
ask students to respond about the target class session. It will be based on an instrument we
developed in our prior research to assess student perceptions of instructors’ use of active
learning and of strategies to reduce resistance and student self-reported resistance to active
learning (DeMonbrun et al., 2017). We have already established the psychometric properties
of those scales (Finelli et al., 2018). The student survey will also include items about student
demographics and background characteristics.

Concurrent with the student survey, we will conduct classroom observations on the day the
target class session in a randomly chosen subset of one-third of the courses (split equally
between the intervention and comparison groups). We are developing a standardized
observation protocol, based on a similar instrument we developed in our prior research
(Shekhar et al., 2015), to examine active learning used in the classroom and the strategies
an instructor uses to reduce resistance. Next steps involve piloting the new observation
protocol and using existing video of faculty instruction to test the validity and reliability of the
scores produced by the observational rubric.

Future work

Future work for this project includes recruiting workshop participants, creating the
intervention and comparison groups, facilitating the three regional workshops each year,
administering the instructor survey to participants in both the intervention and comparison
groups, administering accompanying student surveys, and observing instructors’ use of
active learning in the classroom. We also will explore relationships between instructors’
motivation/behaviour and students’ response to active learning, including students’ affective
response (i.e., value and positivity) and resistance (i.e., participation, distraction, and
evaluation). Finally, we will examine how students’ response to active learning influences
instructors’ future plans to use active learning to better understand the degree to which our
workshop changes instructor motivation and behaviour and to further explore how use of the
strategies can influence student behaviour in the classroom.

Conclusions

Student resistance to active learning is one of the most actionable and least studied barriers
to STEM instructional change. This paper will provide researchers with (1) a framework for
the systematic recruitment of instructors, and (2) validity and reliability evidence for an
instructor survey to assess instructors’ motivation and behaviour related to adoption of active
learning and the strategies to reduce student resistance. This work will also lay the
foundation for future cross-cultural work on adoption of active learning and will provide
valuable insights for faculty professional development. Although student resistance and the
efficacy of our strategies to reduce resistance may vary in different international contexts, we
expect that our methods can be adopted by researchers in any context, and we hope that our
findings will contribute to a broader understanding of student resistance to active learning.
REFERENCES


Acknowledgements

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Taking teaching and learning online: a sequential mixed-methods study of an online chemical engineering module

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Abstract: About 60 second year chemical engineering students were presented with segmented PowerPoint files (with TTS voice and extra animation to simulate lecturing) also saved as MPEG-4 videos in the presence of two tutors during all timetabled lectures of a course instead of lecturer face-to-face. Each segment was followed by questions comprehensively covering content, tutorial questions if applicable, and a question about the next lecture. A learning outcome poorly reached in the first test was identified and linked to the segment where content could be improved, exemplifying a feedback loop of potential use. Module passes and distinctions were compared to those of the past. Perceptions of students were quantified from standard teaching evaluation question statements, as well as an optional open-ended question. To further analyse student perceptions and suggestions qualitatively, three individual student interviews were conducted, resulting in a better impression on how to improve the online setup for future use.

Context of the study

Current trends in engineering education

Brew (2015) indicates that engineering education is impacted by the general reduction of government spending on education and increasing student numbers. At the same time, as indicated by Espinoza (2015), there is increasing pressure on lecturers to publish, meaning less concern for teaching and learning. Online courses could potentially free up time for publishing. Bourne et al (2005) envisaged a blend of online and traditional learning in the future, sometimes all-online. In South African Engineering Education, the move is towards Outcomes-Based Education (OBE), as exemplified in Chetty and Naicker (2017), due to its promotion by accreditation body ECSA, the Engineering Council of South Africa, which followed the development of Engineering Criteria 2000 in the USA; see Felder and Brent (2002).

Drivers for Online Education

In the Fourth Industrial Revolution (4IR), a phrase coined by Schwab (2017), the use of Information Technology (IT) is expected to increase rapidly in all spheres of life, and therefore education as well. Van der Westhuizen (2012) eludes to a concerted drive to implement information and communication technology (ICT) in South African schooling, spilling over into higher education, too. Bourne et al (2005) describes how the Sloan Foundation, a major driving force for online learning in the USA, has set up five pillars of quality online learning: student satisfaction, faculty satisfaction, access, and cost effectiveness. Van der Westhuizen (2012) indicates that some researchers have measured positive effects on education due to ICT, while others found none. Full online lecture implementation by me has passed a first accreditation by ECSA, indicating acceptance by faculty. Regarding the access pillar, our university has organized devices for first year students, as well as Wi-Fi. As far as cost effectiveness is concerned, Bourne et al. (2005) point out that the costs of online learning are comparable with on-campus costs. For further cost savings on inter-institutional cooperation see Bernard, Cao, and Rodriguez (2018).
Obstacles to Setting up Online Lectures

The move to online lectures has its own set of obstacles in addition to normal resistance to change. The setting up of online material takes an immense amount of time and often involves learning of new software, and Becker, Winn and Erwin (2015) think this may present a barrier as most universities value research and publication more than efforts in teaching and learning. In addition, student evaluations after a major change are likely to be poor, discouraging lecturers further if these evaluations are considered for promotion.

A video recording of a classical lecture, such as that for Lauffenburger (2006), can be edited by cutting and splicing; however, major seamless changes to the content will not be possible in future, leaving us with a static product with possible limited shelf life. In addition, not all lecturers may be pleased with being recorded for posterity like this. One way of overcoming this is to use a Text to Speech application to set up a video as Salvor (2016) showed.

Huberts (2017) used PowerPoint in addition to this to create a video; however, more time and proficiency in using PowerPoint animation is required.

In addition to the obstacles to the setting up, there may be a problem of access by students to ICT in Africa as suggested by Yousef et al (2014). In addition, there may be local semiotic reasons why students have difficulty in immersing themselves in ICT, as pointed out by Henning and Van der Westhuizen (2004), and this can be overcome with peer support.

New Developments

According to Yousef et al. (2014), MOOCS and flipped classrooms are reaching an increasing number of students and represent the current future of VBL. They say MOOCs are designed to reach many students, can build and maintain brand, reduce the costs of education, be a potential source of revenue, improve learning outcomes, support innovative teaching and learning, and be used for research purposes. Concerns are that costly teaching assistance may be required, material may be licensed, massive dropout rates are experienced, there is little interaction, test centres are required for certification, and the danger of plagiarism. They state that for a flipped classroom, students can work in their own way and pace for the out of class activities, they can be self-organized and independent, and assistance for students is provided by small groups and lecturer input for the class activities. The concerns are difficulty in providing students with structure to do outside classroom activities, difficulty for them to know exactly what is required for inside and outside classroom activities, and the requirement of creative assessment and feedback mechanisms.

In the work by Huberts (2017), students appreciated the feature that the video could be rewound and played anywhere, anytime. Negative comments regarded the quality of the TTSApp (Text to Speech Application) voice. However, the use of typed commentary, converted to speech using a text to speech App, will facilitate the possibility of different universities collaborating on setting the lectures up online, as changes and augmentations can be converted to speech without having to re-record like with a normal video. These online lectures are succinct due to extra care that can be taken in producing the spoken text.

My teaching

Since I entered higher Education in 2004, my teaching started out as classical didactic, and, under the influence of OBE-based assessor training, I instituted repeatable formative assessments based on learning outcomes not reached by a student in a test. To improve efficiency, these were transferred online, followed by online tests, exams and corrective assessments, the latter which are repeatable test questions, not answered correctly by a student in the original test. This re-usability of the test question (one or more of the variables in the test question is changed each time the test is taken, meaning that the correct answer will be different every time) is an example of an affordance of technology; see discussion by Cope (2014).
The formative and corrective assessments are based on the students' individual test performances, and therefore represent a kind of extreme individualized feedback, as these obligate students to participate in developmental and corrective action. I suspect that these interventions cater for a wide range of student learning preferences and abilities and believe this is reflected in my pass rates that improved to close to 100% for participating students as shown in Huberts (2008). For every 10 hours spent by students on formative assessments, their marks increased by 8% on average; and the number of participating students failing dropped to about 3%.

The development of my teaching may be described as action research as per Johnson (2002) and Tripp (2005), with the steps involving trying something out in a trial, observing the results, reflecting on these, and making further changes for a subsequent trial run or implementation phase.

Research question

My teaching, discussed in the previous section, has facilitated the current (and potentially risky) move to take lecturing, and therefore the whole course, online using technology, because any negative consequences of going fully online were reasoned to be ameliorated by the formative and corrective assessment interventions.

A trial run was conducted with only one lecture being put online: see Huberts (2017). Students rated this slightly higher than a normal lecture. Student academic performance in a subsequent test appeared not to be significantly affected. My online lectures cannot be classified as a MOOC or flipped classroom, as students still attend in a lecture hall, but access simulated online lecture segments using Wi-Fi instead of being lectured to. They answer questions but do this mostly in the lecture venue. The next cycle in the action research was the extension of the one online lecture to include all the lectures. How would students perform academically and react if all lectures were online?

Theoretical framework

The current research forms part of the longer-term action research, which was influenced by OBE, to improve student performance, and 4IR, to employ technology to improve efficiency. Technology may cause tension because, in addition to aiding students by providing e.g. instant feedback and direction, may diminish lecturer-student interaction; not necessarily to the benefit of student performance. To help untangle this, quantitative data and qualitative data are collected and analyzed in this research to aid in the reflection process that is required using a sequential explanatory design; see Creswell (2008).

Methodology

Setting up of the Simulated Online Lectures

Around sixty second year students attended lectures of a Chemical Engineering module according to a university timetable, but instead of having face to face sessions with a lecturer, they used university provided Wi-Fi to access online lecture segments (about 10 minutes each) which were sequentially presented on Blackboard (Bb) as PowerPoint generated videos (see TPRCH4 – Solid Thermal Resistances.mp4 in Figure 1) in the presence of two tutors. These segments contained animation and audio to simulate the way I would lecture and talk to slides. Students also had access to the original PowerPoint presentations (see the example slide in Figure 2), containing the animations shown in the animation pane of the slide, and the transcripts of the audio shown in the notes section of the slide. Each lecture segment was followed by several questions comprehensively covering the presented content, and each had to be answered correctly before the next appeared (see A18(Tutorial1) to A21(Tutorial1) in Figure 1). Automated feedback was offered for incorrect answers. This simulated a lecturer asking questions during a lecture, extended to the
extreme with all students having to answer all possible questions correctly. Simple questions were, on occasion, followed by a tutorial-type question requiring several computational steps to solve. To prepare students, the last question to be answered correctly, before the next lecturing segment would appear, was about that next segment, and here students had to find the answer themselves, for example on the Internet.

![Image](Figure 1: Presentation of the fourth online lecture and tutorials on Bb in the lecturer’s View. The red annotation has been added for explanation.)

In the tutorial question a25 following this slide, students had to use the formula developed in slide no 4 for the thermal resistance of a cylinder to calculate the heat transferred. The values for $r_o$ and $r_i$ were given.

**Lecture Attendance**

Unusual for online modules, students were required to be present in the lecture venue, them being issued with attendance marks which forms part of their semester marks. This is in line
with the author’s underlying philosophy to retain recognizable features of traditional lecturing, hopefully ending up with a blend of good attributes of traditional and online lecturing, and in line with the requirements of a contact university. Other reasons were to avoid overloading students with work outside normal lecturing hours by giving them structure to engage with the course on a regular basis, and to have personal access to peer and tutor support. Only students that worked at a slower pace would have to complete the tasks after hours; on the other hand, students working faster would finish and leave early, or stay to help their peers.

**Setting of Online Tests, Learning Outcomes and Competency**

Two online tests were written after the lectures and following assessments. Students completed the calculations on an answer script, as they would during a traditional test. They would then enter the final answer on Bb. If the answer was correct, they would get full marks and move on to the next question. If not, they were asked follow-up questions, e.g. a formula as in 2a (Figure 3), for which they would get one mark. Hence an electronic record of where students were struggling (or not) was constructed in the module gradebook. Question 2 from the first test, given in Figure 3, was to be used to analyze student learning:

**Figure 3: Question 2 and mark allocation from test 1**

To measure the effect of online lectures on student learning, the reaching (or not) of the learning outcome by students in the second question of the first test following the lectures given above was measured quantitatively. To determine whether the outcomes were reached, the following logic is used by considering the results in the Bb gradebook:

<table>
<thead>
<tr>
<th>Outcome</th>
<th>Description</th>
<th>Reached if the following questions are answered correctly:</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>Calculate thermal resistances</td>
<td>2, 2c, 2cb, OR 2cbb</td>
</tr>
<tr>
<td>B1</td>
<td>Calculate q using thermal resistances</td>
<td>2, 2c, 2cb OR 2cba</td>
</tr>
<tr>
<td>D1i</td>
<td>Use equation q=(T1−T2)/R1</td>
<td>2 OR 2a</td>
</tr>
<tr>
<td>D1ii</td>
<td>Determine T1 and T2</td>
<td>2 OR 2b</td>
</tr>
<tr>
<td>D1iii</td>
<td>Use R1=R1+R2</td>
<td>2, 2c, OR 2ca</td>
</tr>
</tbody>
</table>

**Table 1: Determination if a student reached an outcome**

**Collecting pass and distinction data**

As the module forms part of a new qualification, there is no previous data for the module available to compare student performance. However, the results can be compared quantitatively to previous ones of the lecturer for a range of subjects.

**Teaching Evaluation**

Due to operational issues, students were presented with a standard teaching evaluation just after writing the exam. This is different to what was done in the past, where the teaching evaluations were usually conducted before the exam. The students can answer according to the following scale: Strongly disagree, disagree, agree, or strongly agree. The university
awards marks to the responses, e.g. 4 to “strongly agree”, and hence student feedback can be quantified and compared with previous teaching evaluations of the author. An open-ended question is also routinely asked at the end of the teaching evaluation, where the students can write feedback.

Collecting Student Perceptions and Suggestions

From the teaching evaluation, it was noticed that student perceptions of the simulated online lectures were much lower than would have been expected from the single lecture trial. Hence it was decided to conduct a second phase of research, where three students were selected casually and interviewed after completion of the course to obtain more qualitative data to explain the mostly quantitative data, resulting in a sequential explanatory design. One student was a student leader and came to consultation often, the second was my mentee, and the third was from another (Anglophone) country. Academic performance for the course ranged from a pass after the supplementary exam, a pass, and a distinction (not necessarily in that order). Each of the students was shown an example of a PowerPoint Presentation and the setup of the on-line lecture on Bb. They were then asked (individually) how they experienced the simulated online lecture. After providing the answer, they were asked how they thought it could be improved. The interviews were transcribed and the data combined with the 10 responses received for the open-ended question asked at the end of the teaching evaluation. Three themes were identified (see Braun and Clarke, 2018), and a thematic network was set up with a central theme of perceived support for learning.

Findings and Discussion

Lecture Attendance

Figure 4 shows one of the two peer tutors, who were in attendance during all the lectures, assisting students on the left-hand side, standing. I, the lecturer, was not in attendance. One of the beneficial aspects of contact learning, is the personal interaction of students with each other and with peer tutors, as can be seen in Figure 4. The attendance was 71% on average (excluding 2 tests). For another, similar second year subject of the author, the following attendances were recorded: 81% (2015), 84% (2014), 85% (2013). The attendance at 71% was 10% lower for the online course, indicating that although all content was available online, the benefits of peer and tutor support, as well as attendance marks, resulted in more than 2/3 of students still attending class.

Reaching of Outcomes in Test 1

As stated in the methodology section, the reaching of outcomes A1, B1, and D1 could be determined for each student from their responses to question 2. The average result for each outcome is as follows: A1: 26% of students reached the outcome, B1: 75%, C1:88%; D1i: 30%; D1ii: 46%; D1iii: 54%. For outcome element C1, another question was used, and this
is not further discussed in this work. The worst result was that only 26% of the students were able to calculate the thermal resistance through a spherical solid shape. Looking at the slides and the tutorial question (see Figure 2 and the discussion of the tutorial question 2.15), students were not shown how to calculate the radii, and were simply given the values of the radii in the tutorial question. This may be the problem and can now be corrected by adding such to the lecture slides or tutorial, with the aim to benefit future student cohorts.

As it is a new module, the pass rates of the module with the simulated online lectures, TPRCHA2, are compared to the other modules taught by the author over the years in Figure 5. Considering the whole module, academic performance was on par with previous modules managed by the author with a pass rate of 88% and distinctions of 21%. In considering this result, it should be borne in mind that lecturing for the author's modules comprises 33% of the scheduled time. The remainder is tests, formative and corrective assessments, and the exam. Formative and corrective assessments may have played a major role in countering (any) deficiencies in the online lecture setup.

**Overall Performance in Module**

![Figure 5: Percentage students that passed the courses](image)

It can be seen that the pass rate for the online subject TPRCHA2 was 88%, on the low side compared to other subjects, but still within the range. 22% of students achieved a distinction, also within the range of previous subjects.

**Student Responses to Teaching Evaluation Question Statements**

Satisfaction of students on all 25 question statements in the teaching evaluation dropped from above 3.2 (set by the university as a level below which development is required) for a comparable second year subject managed by the lecturer in the past, to below the score of 3.2 out of 5. This indicated that there is much room for improvement of the online course. The assistance provided by the peer students, the language used, and the availability of the lecturer for consultation scored relatively high.

In the teaching evaluation, where students were asked for additional written thoughts, no mention was made of lack of access to a device during lecturing.

**Coding**

Six positive statements and five negative statements were made regarding the teaching and learning online, without being specific why. The remainder of the results from the Coding of Student Feedback can be summarized in a thematic network (Figure 6). Perceived Support for Learning is the central theme, surrounded by themes of Online Engagement, Explanation (maybe some explanation of what to expect, and what the academic result was in the past, would improve their perceptions as indicated by the question mark), and Human Engagement. Positive and negative comments were included, e.g. 3 positive comments recorded for the “Anywhere Anytime” subtheme of online engagement, and 10 negative comments about the “lecturer” (engagement) subtheme, represented by +3 and -10 respectively in the diagram.
The online engagement theme can be exemplified for animation in a positive way by the one comment of a student during the interview: “the videos were helping cause like they would illustrate what’s happening on the diagram, because if I look at the picture, I would not understand, but when I look at the video, then those illustrations, those motions, give me a better understanding”. And for human engagement during the lecture, another student said, “when you come to a point where you don’t understand, you can’t answer, you can’t ask someone to give you an answer there and then”, indicating that lecturer support or better tutor support was required in class. This network was used to clarify that the students felt they needed more support during the online lecture, as there were more negative than positive comments, and that this support could be provided by better preparation of the peer tutors, more feedback and online help for the tutorials, and periodic presence of the lecturer during the (online) lecture period. This could be used to restore positive student sentiment and, together with satisfying ECSA requirements, this is reasoned to be enough to protect the reputation of the university. In line with the trends in the 4IR, the author proposes that the periodic presence of the lecturer can be online as indicated by the question mark in Figure 6. Tutors and fellow students can provide support for learning with simulated lectures in classrooms; this support is not as obviously available for flipped classrooms or MOOCs.

![Figure 6: Thematic network set up in response to student feedback, indicating areas of importance for simulated online lecturing](image)

**Conclusions and Recommendations**

A single online lecture in a course has been well received by students in the past (Huberts, 2017), but for all lectures online many students feel there is too little interaction with the lecturer, which was also a problem identified for MOOCs according to Yousef et al. (2014). On average, the perceived support for learning is significantly negative, which would normally lead to the abandoning of an intervention. According to the author, the satisfactory academic performance of the students (also reported in the literature for online courses), and the benefits of online lecturing such as concise delivery, potential time-saving once set up, the available affordances of technology, and “moving with the times”, provides impetus to persevere with online lecturing in a contact university context over a long period of time and more subjects. Action research can be used as a means of addressing challenges, such as the perceived lack of student support reported on in this work. Once challenges have been sufficiently addressed, and provided the viability of online lecturing has been established and accepted by all stakeholders, collaboration between contact universities for common subjects may be a possibility.
References


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Research-with-Practice: Insights From Delivering a Workshop
Linking Undergraduate Research, Identity and Epistemic Thinking

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Abstract: During the final phase of a research project, we developed a workshop aimed at introducing engineering educators to our research-based model of students’ researcher identity (how students see themselves as researchers) and epistemic thinking (ways of knowing and understanding concepts) and also enabling these educators to identify ways to modify existing course activities based on this model. This paper describes our research-with-practice (as opposed to research-to-practice) phase, during which we designed and piloted the workshop and used workshop participant feedback to revise how we describe and communicate research insights and outcomes. Outcomes of the research-with-practice cycle include an explicit description of the workshop elements, including how our research-based model was presented to and refined by workshop participants. In addition, we report on feedback about how workshop participants might improve their course activities based on their understanding of the model and insights from our research.

Introduction

We have conducted a multi-phase engineering education research project focused on researcher identities of engineering students who participated in undergraduate research experiences (UREs), and the relationships between their researcher identities (how they see themselves as researchers) and their epistemic thinking (their ways of knowing concepts and their cognitive processes related to gaining knowledge in the context of their research). One of the outcomes of this research project was a model describing the interactions between students’ researcher identity and epistemic thinking called the Dynamics of Researcher Identity and Epistemology Model (DRIEM) (Faber, Kajfez, Lee, McAlister, Ehlert, Kennedy and Benson, 2019). The last phase of this project was designed to be a research-with-practice cycle, where engineering educators would be asked to help translate this model into their courses, and in turn provide insights into ways to better communicate and represent our findings. Although we draw from literature on research-to-practice, we refer to this phase of our project as “research-with-practice” as it involves a feedback loop between the workshop participants and the researchers. This distinction is similar to that between a dissemination
paradigm for translating research to practice, in which “change agents... try to convince adopters that their innovations can help their students,” and a propagation paradigm, that seeks to “engage with adopters early and often to understand their instructional systems and interactively develop a strong product adaptable to specific contexts” (Froyd, Henderson, Cole, Friedrichsen, Khatri and Stanford, 2017, p. 35).

Since a course setting, similar to a research setting, requires students to participate in activities related to the testing, building, justifying, and disseminating of knowledge, we theorized that research identity and epistemic thinking can be formed not only through UREs, but in courses as well. Because our work indicated that research identity could be strengthened or weakened during a URE, we anticipate that research identity can undergo similar shifts in a course environment. The workshop was therefore designed to prompt educators to translate the DRIEM from a research environment into a course environment.

The aim of this paper is to describe the research-with-practice cycle within our engineering education research project and to identify ideas generated by educators for improving their course activities. We asked engineering educators to translate the outcomes from our research project, specifically the DRIEM, from a research environment to a course, so that undergraduate students could progress through the components of DRIEM during a course activity. We explicitly told participants that we anticipated this translation would allow some of the benefits of UREs to be realized by students who may not have access to UREs, however, we did not state which benefits.

Research Questions

This is a work in progress based on data emerging through developing and piloting the workshop. We seek to answer the following research questions:

- **RQ 1:** How can a research-based model (DRIEM) be presented to educators in a way that helps them generate ideas for improving their course activities?
- **RQ 2:** What ideas do educators generate for course activity design based on their understanding of our research insights (i.e., DRIEM)?

These research questions are related to how the outcomes of education research projects can be made relevant to a broad audience of engineering educators. The questions focus on two aspects of the research-to-practice cycle: the insights emerging from research and the educational practice(s) that can be improved through those insights (Karlin, Allendoerfer, Bates, Ewert and Ulseth, 2016). In this study, research insights are gained by workshop participants as they learn about DRIEM and its components. The relationships between the DRIEM components can then be used to inform the design of educational practices such as course activities.

Context

The context for this study is the development of a workshop for engineering educators based on translating the outcomes of a NSF-funded research project, Student Researcher Identity and Transformed Epistemologies (SPRITE) (NSF Award numbers EEC-1531607 and EEC-1531641). SPRITE comprised a mixed methods study of the interactions between students’ researcher identity and epistemic thinking. Our research demonstrates that transformation of students’ epistemic thinking can be influenced by and influence the student’s existing and developing engineering and researcher identities (Benson, Faber, Kajfez, Kennedy, Ehlert, Lee, McAlister and Porter, 2018). Findings from the SPRITE project indicated that undergraduate students saw research as being related to the building of new knowledge. Students described the process of building knowledge within research as being the development of knowledge and included activities related to the testing, building, justifying and disseminating that knowledge.
Theoretical Framework

The basis of this work draws from best practices in the design and implementation of faculty development workshops, the research-to-practice cycle, and participatory action research.

The design of our workshop aligns with practices recommended for engineering faculty professional development programs (Felder, Brent and Prince, 2011). Felder et al. proposed five dimensions of faculty development programs that leverage knowledge of adult learners from Wlodkowski’s theory of adult learner motivation (1999) and our understanding of how people learn (Bransford, Brown and Cockering, 2000; National Academies of Sciences, Engineering, and Medicine, 2018). These five dimensions include expertise of instructors, relevance of content, choice in application, praxis (action + reflection) and group work. The workshop components and evaluation reflected each of these five dimensions, particularly with respect to choice in application, praxis and group work.

The workshop structure was based on the “who/what/how” model of research-to-practice (Finelli, Daly and Richardson, 2014), in which the “who” (participants) were identified as engineering educators at a national engineering education conference, the “what” (content) were the insights from our research project (DRIEM), and the “how” (structure) was an interactive format involving self-reflections, open discussions and classroom simulations (scenarios). The educators were provided with foundational knowledge (basic definitions and descriptions of researcher identity and epistemic thinking), the framework of our research and our research-based model (DRIEM). The nature of the questions we are posing throughout the design, implementation and feedback cycles of the workshop focus on the “what” of the research-to-practice cycle, or what Karlin et al. (2016) identified as research insights and the “how,” or the educational practice(s) that can be improved through those insights (Karlin et al., 2016).

Our final step in fully developing this workshop is a participatory research model in which we as researchers are partnering with the workshop participants. This research approach is modelled after a study by Henderson et al. (2018) in which a conference workshop focused on student argumentation in science courses served as the basis for participatory research that incorporated the participants’ feedback to define current issues and future areas of research on argumentation. The researchers collected and coded artifacts developed by the workshop participants such as posters presented during the workshop and an online blog that was maintained for a short period of time after the workshop concluded. In a similar way, we are collecting artifacts in our workshop in the form of brainstormed lists and comments about our model and how the model relates to course activities, notes from conversations of participants reflecting on experiences affecting their own researcher identity development, and feedback forms completed at the end of each workshop. The data from the workshops will serve to refine the way we present and explain our research-based model and also serve as the basis for understanding how engineering faculty assimilate and use education research findings to impact or change their own practices. Participatory action research is particularly appropriate for studying outcomes of workshops intended to empower participants with an understanding of students’ perceptions of research and their epistemic beliefs, and to impact the participants’ approaches to their own teaching based on what they learned in the workshops. Participatory action research can be defined as “collective, self-reflective inquiry that researchers and participants undertake, so they can understand and improve upon the practices in which they participate and the situations in which they find themselves” (Baum, MacDougall and Smith, 2006). It is an approach that is focused on the idea of reflection and has a goal of enabling action. Action research is described as “creating forms of inquiry that people can use in the everyday conduct of their lives; and action research is part of revisioning our worldview, a paradigm shift, changing what we take as knowledge” (Reason and Bradbury-Huang, 2007, p. 698).
Methods

The initial steps in the research-with-practice phase involved designing and piloting the workshop and associated activities. In this paper we document how we iteratively designed the workshop through the pilot process, and how we collected and used feedback from pilot workshop participants on the workshop structure, workshop content, and their plans for implementing what they learned in the workshop to their courses.

Based on theoretical frameworks related to faculty development and background literature on research-to-practice, we designed the workshop with the following activities: Brainstorming course activities; Reflecting on experiences when participants first felt like researchers; Walking through DRIEM with data examples and its relevance to course activities; Brainstorming ways a selected course activity can be relevant to the components of DRIEM; and Simulating a classroom scenario between instructors/students. These workshop components are summarized in Table 1 and described in more detail below.

Brainstorming Course Activities:

This activity served as an introduction to the workshop and a quick way to have participants generate a range of course activities that would be used as examples later in the workshop. As participants settled in, facilitators asked them to write down as many course activities (such as online homework, term papers, question and answer session) as they could onto sticky notes. Facilitators encouraged participants to identify course activities that participants found in literature, seen colleagues implement, or implemented themselves. Facilitators then collected sticky notes and grouped them into similar types of activities for use later in the workshop.

Reflection on First Research Experience:

This activity was intended to help orient workshop participants to the perspective of being a new to research. Facilitators used prompts similar to those used in the research project to help participants recall their first research experience. To help guide the reflection activity, facilitators invited workshop participants to think of the first time they felt like a researcher and to identify elements of that experience such as what they were doing, who they were working with, and how they determined what to work on. Facilitators then asked participants to share these research experiences, which helped to contextualize the discussion about the definition of researcher identity.

Introduction to the Dynamic Researcher Identity and Epistemology Model (DRIEM):

The workshop facilitators presented the DRIEM to participants by first explaining the overall model followed by a description of individual components of the DRIEM:

- Student research actions
- Social interactions between student and others
- “My knowledge of how research works”
- “My understanding of what a researcher does”
- “This is how I see myself as a researcher”

During the stepwise presentation of the DRIEM, participants were given time to reflect on each component and identify ways to incorporate them into engineering courses. Finally, the research experiences of two participants were described to illustrate their progress through the DRIEM during their UREs.
Table 1: Summary of workshop components and their objectives

<table>
<thead>
<tr>
<th>Workshop Component</th>
<th>Objective</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Brainstorming course activities</td>
<td>Generate a list of potential course activities to adapt or revise</td>
<td>Prompt participants write ideas for course activities (research reports, online homework, etc.) on sticky notes</td>
</tr>
<tr>
<td>Reflection on first research experience</td>
<td>Get participants to adopt the attitudes and mindsets of their students as being new to research or feeling like a researcher for the first time</td>
<td>Prompt participants to reflect on an experience when they first felt like a researcher, and what made them feel like a researcher</td>
</tr>
<tr>
<td>Introduction to the Dynamic Researcher Identity and Epistemology Model (DRIEM)</td>
<td>Present overview of our research-based model of the interactions between epistemic thinking and researcher identity</td>
<td>Explain each component of DRIEM, providing examples of experiences students considered as research, and how those experiences relate to their beliefs about knowledge</td>
</tr>
<tr>
<td>Examples of Course Activity Design</td>
<td>Translate DRIEM components from a research context to a course context</td>
<td>Present an example of a course activity, such as online homework, and describe how it could be modified to facilitate student progress through one or more components of the DRIEM, i.e., providing students with opportunities to build, test, justify, or disseminate knowledge</td>
</tr>
<tr>
<td>Participant-Generated Ideas of Course Activity Design</td>
<td>Co-construct course activities that utilize the DRIEM</td>
<td>Prompt participants to identify a course activity they will be designing or redesigning to give their students opportunities to progress through one or more DRIEM components. Facilitate a group discussion of why/how the proposed activities incorporate insights from DRIEM</td>
</tr>
<tr>
<td>Classroom simulations</td>
<td>Provide a scenario that helps participants visualize the implementation of the DRIEM-related course activity</td>
<td>In groups, participants describe and discuss a scenario of instructor/student interactions during a course activity in which students progress through the DRIEM components. Groups identified and discussed instructor actions, reflection prompts, and students’ questions or concerns. Guide participants to draw on the DRIEM to support and determine their actions as instructors</td>
</tr>
</tbody>
</table>

Examples of Course Activity Design:

This part of the workshop was informally referred to as “Living the DRIEM” as we described how the DRIEM could be enacted through a course activity. Using an example that would be familiar to most of the participants (online homework), facilitators mapped aspects of this course activity to each component of the DRIEM. This served to demonstrate what participants would be expected to do in the next part of the workshop.
Participant-Generated Ideas of Course Activity Design:
In this activity, participants identified a single course activity, either their own or one proposed during the brainstorming activity at the beginning of the workshop. Facilitators then asked participants to use their knowledge of the components of DRIEM to design or redesign the activity in a way that would allow their students to progress through one or more components of the DRIEM. Workshop participants were allowed to break the course activity into smaller assignments if needed and were encouraged to start on the DRIEM component they felt most comfortable with. Participants were asked to identify how the instructor should introduce and explain the course activity. Facilitators encouraged workshop participants to contextualize the assignment to highlight aspects such as how it would help build students’ knowledge and their roles as knowledge builders, or provide opportunities to share what they know, to help clarify DRIEM components for their students. The workshop participants were encouraged to envision students’ questions or concerns about the activity and what the instructor would ask them to do and reflect on. Through a group discussion lead by the workshop facilitators, participants shared their ideas and considered others’ perspectives as they began brainstorming how to apply the DRIEM in their own courses.

Classroom Simulations:
Back in small groups, participants selected a course activity from among those they designed or redesigned, and to describe and discuss a scenario in which it is facilitated in a classroom:

- Where does the scenario take place (classroom, course laboratory, alternative learning environment, library, etc.)?
- Who is involved in this scenario (i.e., instructor, teaching assistant, students) and what role are they playing (for example, a reluctant student, an eager student, an instructor who designed the activity, an instructor who was told to do the activity)?
- How could the instructor introduce and explain the course activity such that students understand why it is important, and how it will help build their knowledge, their role as knowledge builders, their opportunities to share what they know, etc.?
- In what ways could the instructor introduce and explain the guidelines for the course activity to incorporate components of the DRIEM, and to provide opportunities for their students to progress through components of the DRIEM?
- What questions or concerns would students have about this course activity and the things the instructor is asking them to do or reflect on?

Feedback and Data Collection:
Facilitators monitored groups as they worked out the scenarios and provided feedback, particularly with respect to connecting the course activity with components of the DRIEM, and kept field notes of their observations of the workshop activities. Feedback was also collected through the online blog, starting with the prompt, “Please share your thoughts stemming from the workshop.” Additionally, feedback was collected through a post-workshop questionnaire, with prompts such as "What specific changes will you make in your class activities after this workshop?" and "What are three key challenges to applying DRIEM in a classroom environment?" Feedback and workshop artifacts (participant-generated posters and notes, facilitator field notes) were analyzed to identify common themes about applying information from the workshop and how to better communicate the DRIEM to educators.

Implementing the Workshop
The workshop was facilitated by members of the research team, who shared responsibility for presenting the materials, facilitating discussions, and taking notes about how participants were interacting with the workshop materials and activities. Participants were provided handouts with information and/or guiding questions for each component of the workshop, as well as handouts with background information and the underlying concepts for the SPRITE
project. Feedback forms were distributed at the end of the workshop that asked participants for comments on their understanding of the underlying research concepts (research identity, epistemic thinking) and research insights (components of DRIEM), clarity of workshop presentations and materials, the changes they plan to implement in their course activities based on what they learned in the workshop, key outcomes they could achieve when applying DRIEM in a classroom environment, and key challenges to applying DRIEM in a classroom environment.

The workshop has been piloted three times to multiple audiences, including engineering education graduate students and STEM faculty members. The first two iterations of the workshop were provided in a 75-minute timeframe and the third was 180 minutes in length. At this time (in the pilot phase of workshop development), these materials are being used to refine the way we present and explain our research-based model.

Findings and Conclusions

We anticipated that participants would leave our workshop with the tools provided from our research insights to incorporate aspects of the DRIEM in their engineering course activity designs. Because we are still in the pilot phase of this workshop, we cannot fully answer our research questions. However, as a work in progress, insights into RQ 1 (How can a research-based model (DRIEM) be presented to educators in a way that helps them generate ideas for improving their course activities?) are emerging from participant feedback. This feedback showed that the workshop activities prompted participants to envision the students in their courses as potential researchers and to reflect on the challenges and benefits of implementing these activities in a classroom environment.

Similarly, insights into how to answer RQ 2 (What ideas do educators generate for course activity design based on their understanding of our research insights (i.e., DRIEM)?) were gained from our pilot workshops. Perhaps because there were too few participants to conduct the classroom simulation activity, in general participants did not come up with specific course activities during the pilot workshops. Rather, they had general ideas about rephrasing problems and incorporating reflection in online assignments to get students to think about what it means to do research and become researchers.

We aim to help educators understand what epistemic thinking is (i.e., the nature of knowledge, or individuals’ epistemic aims such as gaining knowledge, forming beliefs, seeking truth), how it manifests through student practices in engineering courses, and how it interacts with student identities. With the understanding that epistemic cognition is contextual (i.e. it is elicited and expressed differently in different disciplines), we cannot dictate to participants what kinds of epistemic cognition are productive. Thus, we co-constructed ideas for classroom activities with workshop participants to reflect discipline-specific epistemic cognition, leveraging participants’ knowledge of their specific contexts and topics. Based on feedback from participants in our pilot workshops (a total of nine participants to date), it was important to take the background of participants (i.e., engineering educators teaching different level courses) into consideration when presenting example activities. For example, incorporating research actions into engineering problem sets was more difficult to envision for instructors of first year courses compared to upper level or capstone course instructors.

Through the process of presenting the DRIEM to workshop participants, the research team has reconsidered and redesigned its visual representation and text descriptions of the DRIEM components and how they are related. The workshop allowed us to think about how we present and describe our model, going beyond what we are able to do in research team meetings, reports and papers. There was value for both educational practice as well as research, or a reverse effect of practitioners’ observations and feedback on the way we are describing and presenting our research. This effect goes beyond research-to-practice or dissemination and has reinforced our decision to refer to this phase of our research project.
as “research-with-practice” as opposed to “research-to-practice.” This further sets the stage for participatory action research, with future workshop participants co-constructing the ways we interpret and communicate our research findings to a broad audience.

The main findings of this work to date can be summarized as follows:

1. Orienting workshop participants towards students’ perspectives and experiences by having them reflect on the first time they felt like researchers was effective in prompting participants to view their students in a different light and to think about classroom activities from a student-centered point of view.

2. Having workshop participants and facilitators co-construct ideas for classroom activities provided opportunities to demonstrate context-specific examples of epistemic cognition for a variety of disciplines, which can be useful for future research on epistemic cognition and epistemic cultures within disciplines.

3. Feedback from workshop participants on aspects of the research-based model (DRIEM) that were difficult to understand or apply helped facilitators refine the visual representation and explanation of our model. This extended this project from research-to-practice, wherein insights emerge from research and applications of those insights to educational practices are identified, to research-with-practice, wherein the researchers benefitted from practitioners’ insights as well.

**Implications and Future Work**

There are two main implications of this work for both education practitioners (instructors) and education researchers who seek to close the gap between research and practice. Both implications are important for education research projects that seek to impact educational practice.

1. Adopting a research-with-practice approach was productive; presenting research findings in a workshop that afforded opportunities to co-construct ideas for applying those findings produced ideas that neither practitioners nor researchers could have developed independently.

2. Orienting participants to students’ perspectives and experiences was effective for producing student-centered classroom activities.

Future research plans include exploring ideas for course activities generated by educators in our workshops and how those ideas relate to epistemic thinking, research identity or the synergy between them. We have sought to engage workshop participants in providing feedback for evaluating the workshop effectiveness and outcomes. In the future, we will also ask participants to engage in workshop-related research that examines the outcomes and impacts of the workshops on their beliefs and practices related to teaching. In a similar way, we will analyze artifacts from our workshop in the form of brainstormed lists and worksheets on which participants comment on the DRIEM. Future work includes coding these artifacts based on our theoretical frameworks and on concepts from our research, for example examining if they contain ideas related to epistemic thinking, research identity or synergy between these. We also plan to look for possible connections between how participants viewed their students and the general ideas they came up with for classroom activities. For example, we will examine whether thinking of students as “unexpected researchers” affected how participants thought about prompting and implementing written reflections.

It should be noted that the larger research project was conducted entirely within U.S. institutions (i.e., URE participant data collection and analysis as well as pilot workshops). We anticipate that both the DRIEM and the ways that engineering educators incorporate DRIEM into courses might be influenced by the research culture found in non-U.S. higher education institutions relative to U.S. institutions.
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Towards a collaborative strategy to research the teaching of ethics within the engineering curriculum across South African higher education institutions

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Abstract: Engineering ethics provides a trans-disciplinary focus for a research project linking the different engineering disciplines within engineering education. Engineering ethics is positioned as providing a context and rationale to the technical skills and knowledge developed throughout the engineering curriculum.

This research project aims to identify differences in conceptual approaches to the teaching of ethics within engineering. The paper focuses on developing a conceptual framework for the teaching of ethics within engineering that models a collaborative research methodology.

An expanded conception of the teaching of ethics within engineering provides the opportunity to demonstrate synergy between the teaching of ethics within engineering and the Engineering Council of South Africa’s (ECSA) Exit Level Outcomes (ELOs). This provides a context to the pilot project research into the tools and strategies for teaching ethics to engineering students, in preparation for a longer-term project.

Context
Ethics is positioned as a key aspect of conduct for professional engineers, and research into ethics education was identified as a significant area of potential research at the plenary of the 2017 South African Society of Engineering Educators (SASEE) Conference.

In this context, the Engineering Council of South Africa’s Code of Conduct (ECSA 2017), covers the responsibilities of engineers in general from an individual and professional perspective. In addition, the different professional engineering organisations, covering different disciplines of engineering in South Africa, have their own codes of conduct governing the conduct of individual members. Engineers define their professional obligations and conduct within industry, or specific disciplines, in the related codes of conduct of professional bodies: for example, the South African Institute of Civil Engineers (SAICE 2017), the South African Institute of Architects (SAIA 2010) and the Institution of Chemical Engineers (IChemE 2015).

Improved corporate governance in South Africa, highlighted in the various formulations of the King Code (I-IV), has driven legislative reform of corporate and entrepreneurial obligation in South Africa over the past twenty-five years. This is effected in the intentional closing of procedural loop-holes that allowed individuals and corporations to avoid fiduciary and other responsibility. In this regard, legislation such as the South African Companies Act highlights the importance of ethics and requires the ethical obligation of individuals and companies.
Ethical conduct can consequently be seen as a visible measure of the success of legislation governing how businesses operate across industry in South Africa – across engineering disciplines.

In the South African environment, the requirements of the Engineering Council of South Africa prescribe eleven areas described as exit level outcomes (ELOs) that need to be addressed within the engineering undergraduate curriculum, and the levels at which these need to be achieved. Because the nature of exit level outcomes is explicitly concerned with results rather than process, it is possible that the teaching and learning process for a cross-cutting topic such as ethics is not clearly articulated.

ELO 10, that of engineering professionalism, engages explicitly with ethics and professionalism, and requires students to comprehend, apply and commit to ethical principles, professional ethics, responsibilities and the norms of engineering. Problem solving (ELO 1), requires students to demonstrate the competence to identify, formulate, analyse and solve complex engineering problems creatively and innovatively. Although not explicitly articulated, ethics may be positioned at the core of the process of problem-solving. Problem-solving furthermore is key to both the application and design of systems. Several other exit level outcomes engage more implicitly, but importantly, with ethics:

- ELO 6, that of professional and technical communication, requires students to demonstrate competence to communicate effectively, both orally and in writing, with engineering audiences and the community at large. This requires engagement with the legitimate use of persuasion and argument which are ethical concerns.
- ELO 7, that of the impact of engineering activity, requires students to demonstrate a knowledge of sustainability and an understanding of the impact of engineering activity on the society, economy, industrial and physical environment, and to address issues by defined procedures. These aspects are fundamental to a broad understanding of ethics.
- ELO 8, that of individual, team and multidisciplinary working, requires students to demonstrate the competence to work effectively as an individual, in teams and in multidisciplinary environments. The process of developing professional and respectful relationships with stakeholders is core to ethical practice.
- ELO 11, that of engineering management, requires students to demonstrate knowledge and understanding of engineering management principles and economic decision-making. This introduces multiple areas that relate to ethics from both a relationship and process perspective.

Ethical conduct and responsibility can consequently be identified as a key concern of engineering education in South Africa, linking professional and civic responsibilities. It is an area of the engineering curriculum that cuts across disciplines, ELOs and levels of qualification. It is therefore to be expected that the curriculum of engineering undergraduates addresses ethics in different ways at different points in the curriculum. What is not evident is how ethics is defined in the different contexts, how ethics is understood by practitioners and how this influences the approaches to teaching ethics within different institutions and across engineering disciplines.

Harris, Pritchard and Rabins (2000) position learning about engineering ethics as much a part of what engineers know as factors of safety, testing procedures, or ways to design for reliability, durability, or economy. Engineering ethics is part of thinking like an engineer. Teaching engineering ethics is similarly part of teaching engineering (Harris et al, 2000).

In a study of alternative approaches to teaching ethics to engineers, Bowden identified the following constituents:

- case study teaching.
- ethical theory.
- acting in the public interest (or whistle-blowing).
- codes of ethics.
- the role of the professional society. (Bowden, 2010).
Extending knowledge of ethical issues is seen to empower the professional body, individuals in the workplace, as well as lecturers and students in the classroom (Bowden, 2010).

Watkins emphasises the way in which people handle everyday issues such as safety, access to information, intellectual property, handling data, career credentials, work environment, etc. as constitutive of the reputation of the professional (Watkins, 2015). Ethics is seen to be an area that can be approached in such a way as to provide a context to and rationale for the technical skills and knowledge developed elsewhere in the curriculum. Alternatively, it is also an area that can be neglected and side-lined – with significant consequences in the public spaces of engineering projects and the engineering industry.

Conceptual framework

Making the distinction between what is taught and what is learned, Wright’s 1995 literature review explores whether moral judgement and ethical behaviour can be learned. Wright situates himself as seeking to justify the link between learning and moral development and proceeds to identify and discuss the alternative approaches without definitively answering his own question. It is evident that, although he bases his analysis on Kohlberg’s theory of cognitive moral development which is situated in the behaviourist tradition, Wright does not provide a clear theoretical framework to what constitutes learning. This affects the depth of his analysis. His insights regarding the way behaviour is socially conditioned, anticipate a focus on learning communities and the role of discourse in ethical conduct.

Meyer and Land (2005) identify ‘threshold concepts’ that operates both within and across disciplines and, as such, form a ‘conceptual gateway’ to understanding. They identify the threshold as “the entrance to the transformational state of liminality” (Meyer and Land 2005:380) that is essentially tentative and exploratory. In relation to engineering undergraduates, ethics is positioned as one of Meyer and Land’s ‘threshold concepts’ that operates both within and across disciplines and as such forms a ‘conceptual gateway’ to understanding that may be ‘transformative’, ‘irreversible’ and ‘integrative’ involving “critical moments of irreversible conceptual transformation in the educational experiences of learners, and their teachers” (Meyer and Land 2005:373). As such, generative engagement with the concept of ethics is seen to open a new landscape of possibilities for those in the engineering profession. Meyer and Land recognised the way in which a “shift in perspective” is often associated with an “extension in the use of language” and a “shift in subjectivity [involving] a repositioning of the self” (Meyer and Land 2005:374).

This connects graduates’ developing identity as engineers intimately with their sense of professional and ethical responsibility in a way that is necessarily exploratory and transformative. Meyer and Land juxtapose the validated requirements of professional bodies and other stakeholders with vested and pragmatic interests with the exploratory nature of learning they posit (Meyer and Land 2005:379)). This contrasts the achievement of defined professional outcomes with a more tentative reaching for meaning that is characteristic of the journey of understanding beyond the conceptual portal. This emphasises the inter-relatedness of the learner’s identity with thinking and language (Meyer and Land 2005:379) in a way that highlights the importance of community and discourse in establishing consensus and norms.

Meyer and Land connect their theory of threshold concepts with a particular view of education as constructed within context, discourse and community. They challenge Biggs’ confidence in advocating that the learning environment be “suitably ordered” using… “constructive alignment” (Biggs, 1999) as a strategy for optimising learning, with Ellsworth’s view that posits the value of the uncomfortable spaces where students learn despite the complacence of the intended learning outcomes (Ellsworth, 1989). Meyer and Land define a liminal space existing within the learning journey as generative and productive for learning.
With reference to an Australian experiment relating to threshold concepts in economics, Meyer and Land highlight the operation of different stages of learning (involving “naive interpretation”, “false proxy”, “ritualised learning” or “mimicry”) where the “promise of learning” is curtailed almost as soon as the learning journey is embarked on without engaging with the concept’s potentially transformative potential’ (Cousin 2003). Meyer and Land are keen to ensure that the openness of meaning and significance is retained and situate this within a discursive context where meaning develops within community and contexts rather than being pre- or post-determined.

Davis (2006:721) emphasises the impact of a shared discourse and the regular profiling of ethical issues and standards of conduct in developing a sense of professional identity. Key to the shifting of perspective and to developing consensus around the importance of ethical issues is the knowledge that one shares with other engineers a commitment to a particular standard of conduct and a sense of a standard’s reasonableness. Davis highlights the relationship between professional group identity and individual conviction in persuading others and, potentially, winning support and commitment to act ethically where he argues persuasively for the value of classroom discussions concerning ethics and professional responsibilities in highlighting both the reasonableness of standards and their consensual basis (Davis 2006:721). Davis endorses Rest’s identification of four desirable outcomes for the teaching of ethics. These are seen to comprise:

- improved ethical sensitivity
- improved knowledge of relevant standards of conduct
- improved ethical judgment and
- improved ethical willpower (that is, a greater ability to act ethically when one wants to) (Rest quoted by Davis 2006).

In contrast, Pfatteicher poses the question: “What is ethics instruction supposed to do?” (2001:136) in a way that deliberately defines learning to exclude attitude or values. The focus of attention falls on defining the objectives of ethics instruction and on the outcomes the students can be expected to demonstrate. Her answer: “[T]each but do not test what is learned or applied, just what is known”, connects implicitly to educational outcomes outlined by Bloom where he distinguishes between the recall of knowledge, understanding and the application of knowledge. Pfatteicher limits the responsibility of teaching ethics by defining that, “strictly speaking, the criterion does not require programs to demonstrate that graduates are ethical; it requires that they understand professional and ethical responsibilities” (2001:137). This shifts the focus of ethics education so that ethical behaviour becomes the object of study rather than its objective. Pfatteicher consequently defines the role of teachers as providing input and evaluating students on their knowledge and skills rather than their values and beliefs. (Pfatteicher 2001:137). She sums up the goal of ethics education as improving students’ ability to think about ethics “without obliging … [educators] to grade students on their ethics” (Pfatteicher 2001:138). This approach is to some extent supported by the ECSA exit level outcome that requires students “to demonstrate critical awareness of the need to act professionally and ethically”, rather than “to be professional and ethical”.

Engineering ethics can be critiqued as furthering an individualistic approach to problem-solving in both its teaching and methodology (Conlon and Zandvoort 2011). Conlon and Zandvoort identified part of the reason for individualisation being the temptation to define context in a narrow way in order to resolve a problem effectively. Conlon and Zandvoort query whether this is effective preparation for making ethical engineering decisions in complex situations.

The context of South Africa, with its culture of collective decision-making, provides an ideal opportunity to develop an approach to engineering ethics that complements the emphasis on individual solutions or solutions for individuals. In its recent history, South Africa has knitted together a collaborative approach which has contributed innovative and satisfying solutions
to pernicious problems (see the Freedom Charter, the negotiated settlement and the South African Constitution). In all these areas, solutions were crafted out of a tenacious and hopeful solidarity, despite huge challenges.

Rather than challenging the practice where individuals are the focus of engineering ethics education, Conlon and Zandvoort require individuals to be considered as part of a social, organizational, legal, as well as political context (Conlon and Zandvoort 2011: 220), where an individualistic approach to engineering ethics is seen to fall short of providing students: “with appropriate knowledge and skills for understanding that context and for understanding which changes might be needed and why” (Conlon and Zandvoort 2011: 226). Here the rationality of closed and controlled technical systems is positioned at odds with the complexity of real systems.

The above discussion demonstrates the significance of the conceptual framework for the teaching of ethics to engineers, allowing educators to position themselves with very different purposes. This framework affects how teaching is conceptualised and assessed.

Research questions and objectives

This research project emerged from a newly developing personal conviction that over-reliance on the traditional model of individual scholarship and research into the teaching of ethics to engineering under-graduates was unsatisfactory as it replicated an individualised model of teaching and learning that did not, in practice, reflect how teaching or learning (or research) takes place. Traditionally, this endorsed an individualistic understanding of ethics that kept the individual as the focus and subject of ethical theory rather than opening ethical theory to include community and discourse as significant facets of what it is to be ethical. The challenge became a methodological one of how to investigate the teaching of ethics in a way that opened the research project to different voices and approaches in an effective way.

The motivating and personal quest, ‘How best to teach ethics?’ was effectively translated into a project where obtaining the information around ‘How ethics is taught within engineering faculties at South African institutions of higher education?’ provided an initial catalyst to engage engineering educators’ interest and attention. This was seen to provide the opportunity to initiate a learning community focused on identifying opportunities to teach ethics within under-graduate engineering and fostering the pursuit of innovation and excellence in the teaching of ethics in a collaborative way. This question is significant in order to ascertain how South African engineering educators understand and conceptualise the teaching and learning of ethics in relation to the preparation of students as engineers. Associated with this question is another question involving querying the extent to which it is a required part of teaching ethics to ensure that engineering graduates and professionals behave in an ethical way? And if ethical conduct is a goal of teaching, how would that be defined and assessed? Another related question concerns what model of learning supports an action research project investigating the tools and strategies involved in the teaching of ethics within the engineering curriculum involving both engineering students and lecturers.

The research question thus becomes how to design a research project in engineering ethics that encourages collaboration, empowerment and transformation. The research project needed to be open-ended and to be flexible enough to involve multiple stakeholders and contributors. It furthermore needed to appeal to busy academics, many of whom would be professional engineers.

This research seeks to situate the learning that takes place within the curriculum and looks at aligning teaching and learning activities with learning goals. The intention of this research in engineering education is to foreground the teaching of ethics relating to engineering education at different institutions of higher education in South Africa. It aims to examine how ethics is taught and the strategies and tools that engineering educators use to support their teaching. It draws attention to the process of teaching and the way in which tools can be used. The research aims to generate focused attention on the teaching practice relating to
ethics, with the assumption that increased attention to, and reflection on, practice, combined with better collaboration amongst practitioners, can improve practice. It looks at where ethics is taught in undergraduate engineering education and situates these practices relative to key ECSA documents in order to see how ethics is being translated in practice.

The objectives of this research project are thus to:

- generate new knowledge regarding current practices concerning the teaching of ethics to engineers within higher education institutions in South Africa
- assemble examples of different approaches to the teaching and learning of ethics in use within undergraduate engineering education in South Africa
- profile the process of generating the new knowledge as part of a strategy to engender interest in and reflection as regards the process of teaching ethics
- contribute to strengthening teaching around ethics through enhancing reflective practice
- develop a community of engineering educators consciously engaged with the challenge of how to ensure students engage critically and reflectively with issues that relate to ethics.

The research investigates where ethics is addressed within the engineering under-graduate curriculum and how this is conceptualised. An audit of what is currently taught is thus an important part of establishing the value and impact of teaching ethics within engineering.

**Methodology**

Research strategy can be positioned as a potentially powerful tool to affect practice and to transform context. This recognises that the research strategy itself is part of the research process in significant ways that affect goals and outcomes. Methodology is, by definition, procedural. It appeared necessary for the methodology of this research to be inclusive of the different voices and different contexts. Methodology became a focus in this research following Smagorinsky’s challenge that the method section “be clearly aligned with the framing theory and the rendering of the results” (2008:392). Smagorinsky further emphasised the significance of relationship in (social science) research and the need to account for positionality, including “the social and cultural experiences of the participants; the physical, social, and political setting of the research; the assumptions at work in the environment; the researcher's relationships and interactions with the participants; and much more” (Smagorinsky 2008). He recommends that: “research into the teaching of ethics also needed to consider relationships to a greater extent than perhaps had been the case in past approaches” and draws attention to the “need to implicate method in results, presenting authors with new obligations as they wr[i]te their articles” (Smagorinsky 2008: 392).

Action research was selected as an option for a research methodology as it provided the opportunity to open the research process and the participants to being changed by participation in the research process. Action research is a “critical educational research methodology looking to foster change in social practices” within particular contexts, where the “aims and benefits of action research are strategic improvement of practice” (Case 2011: 196). This sits well with an engineering education project aiming to improve the practice of engineering ethics education at South African institutions. Action research vitally involves research with subjects, not on them (Case 2011:196). This encourages the research plan to create opportunities for the input of participants at all stages of the research process. Action research has several key affordances that were seen to be of value in a project like this: it is collaborative; it takes place over an extended amount of time; it is intentionally innovative and potentially transformative of people and environments. Case recommends this type of research as effective for engineering educators who are: “interested in systematically researching their own educational practices but also in implementing substantial personal and social change in their practice” (Case 2011: 197).

Various models of learning could be used to support the action research project into how ethics is taught within undergraduate engineering education. Bloom’s and Kohlberg’s models of learning have been mentioned in connection with relevant approaches to the teaching of
ethics. Fink’s theory of significant learning was selected as appropriate support for the educational aspects of the project as Fink seeks to define learning beyond understanding and application and to incorporate as part of his model the human dimension, including emotional commitment shown in caring. This was seen to dovetail with an approach seeking to extend the scope of ethics teaching within engineering beyond that of knowledge and recall and to include values and attitude. Fink identifies six types of learning that he distinguishes in the following manner:

- Foundational learning – the ‘set of facts, principals and relationships… that constitute the content of the course’
- Application – what students need to do with the knowledge they have: may involve ‘problem-solving, decision-making or creative thinking’
- Integration – establishing similarities and interactions across disciplines
- The human dimension – student learning about themselves
- Caring
- Learning to learn (Fink 2003).

Fink’s concepts are seen to relate learning to the acquisition of knowledge and skills, the integration of concepts and of values and attitudes. Fink’s model of significant learning is seen to provide appropriate support for an action research project investigating the tools and strategies involved in the teaching of ethics within the engineering curriculum involving both engineering educators and students.

**Findings**

This paper details the initial stages of the research project and forms part of the pilot process testing the method and the suitability of the selected approach utilising Fink’s theory of significant learning (Fink, 2003). It relies on a small sample of data obtained from engineering educators at two institutions in South Africa where undergraduate engineering degrees are offered. These institutions are the University of Cape Town (UCT) and Durban University of Technology (DUT). One institution is historically advantaged and offers Bachelor of Engineering and Bachelor of Science in Engineering degrees. The other institution has transitioned into a technical university offering both a National Diploma in Chemical Engineering and a Bachelor of Engineering Technology degree.

The initial process required the development of the questionnaire and preparation of a rationale to request educator consent for questionnaire responses to be used in the data collection. Subsequently, ethics clearance was applied for and received. At each institution, 14 engineering educators from across the range of engineering disciplines were approached to fill in questionnaires. The participants were selected because of their interest in engineering ethics and/or engineering education. Of the fourteen approached, eight responses were received from one institution and three from another. Data from the questionnaire was collated in terms of the institution and the categories of questions asked. Questions were grouped into categories that elicited:

A. information about the specific department where the educator is situated, the courses taught/convened, the level (first, second, third or fourth year) and the extent to which the course engages with and assesses ethics (Questions 1, 2, 3, 5, 6, 9, 10, 21)

B. information about the educator’s responsibility for and attitude to the teaching and learning of ethics for undergraduate engineers (3b, 8)

C. whether the educator considers themselves equipped to teach ethics – and what that background might include and how the teaching of ethics to engineers may have changed their sense of professional identity (17, 18, 20,

D. the educator’s definition of ethics and approach to teaching ethics (4, 7, 19, 22)

E. details of learning activities, instructional strategies and tools for the teaching of engineering ethics, both those in use and those known to have potential use (11, 12, 13, 14, 15, 16).
Sections A is seen to collate information concerning the educator’s position within the engineering faculty and the range of courses taught, as well as their understanding of the degree to which the courses address and assess ethical issues. Sections B and C expand on an understanding of the positionality of the educator with regards to teaching ethics to engineering students. Section D collates formulations from the educator that detail the educator’s definition of ethics and their strategy in and vision for the teaching of ethics. This section also presents a table for the educator to fill in that requires the educator to formulate a range of aspects relating to the teaching of ethics. Section E uses concepts from an educational context to elicit engagement with, and reflection about, teaching practice.

This stage of the research utilises the responses from the pilot study to the five categories of questions listed above, in order to assess the adequacy and usefulness of the questionnaire in achieving the aims of the research. The preliminary findings show that all respondents viewed the teaching of ethics to undergraduate engineers as an important and significant part of the curriculum, with one respondent specifying the importance of the teaching of engineering ethics rather than ethics in general. This response demonstrates the need to identify more clearly the scope of teaching ethics to engineers.

The following table lays out five alternative understandings of ethics presented: ethics as concept, knowledge, skill, value and attitude. Samples of answers from the questionnaire responses are included to give a sense of the range of engagement with the alternatives.

**Table 1: Conceptual Framework showing different alternative approaches to the teaching of ethics**

<table>
<thead>
<tr>
<th>Ethics as concept</th>
<th>Ethics as knowledge</th>
<th>Ethics as skill</th>
<th>Ethics as a value/destination</th>
<th>Ethics as an attitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>To act ethically</td>
<td>Codes of conduct</td>
<td>How to reference</td>
<td>Social justice</td>
<td>Respectful</td>
</tr>
<tr>
<td>To be ethical</td>
<td>Standards of practice</td>
<td>How to analyse a problem</td>
<td>Fairness</td>
<td>Honest</td>
</tr>
<tr>
<td>To have ethics</td>
<td>Case studies</td>
<td>How to build an argument</td>
<td>Care</td>
<td>Fair</td>
</tr>
<tr>
<td>Self</td>
<td>How to make judgments</td>
<td>Positionality</td>
<td>Collaborative</td>
<td></td>
</tr>
<tr>
<td>Right and wrong</td>
<td>How to make decisions</td>
<td>Excellence</td>
<td>Integrity</td>
<td></td>
</tr>
<tr>
<td>The law</td>
<td>How to work in a multi-disciplinary team</td>
<td>Transformative/ion</td>
<td>Professional</td>
<td></td>
</tr>
</tbody>
</table>

In this table, ethics is positioned in distinct ways, as:
- a concept that operates within the boundary of language
- knowledge or skill that can be acquired or owned
- part of personal or professional or corporate identity relating to values and attitude.

These alternatives have implications for what is taught, how teaching takes place, what is learned and how that learning is assessed.

**Conclusions**

Initial results of the pilot sample suggest that, although ethics is viewed as important, there is a wide range of understanding concerning what ethics is considered to encompass. Significantly, very few of the course outlines explicitly address ethics in either their outcomes or assessment procedures. Ethics was recognized as important because it intersected with many aspects of professional practice and academic process. Ethics is seen to be addressed implicitly in areas such as referencing, team-work, the attitude to work and
handing in of assignments. The exception to this is the explicit fourth-year requirement within the degree programs that require the assessment of competence in exit level outcomes such as ELO 7 and 10 relating to engineering professionalism and the impact of engineering on the environment and society.

It was interesting to note that the educators in the main viewed themselves as ill-equipped to teach ethics. These responses relate to the respective educator’s assumption of the scope and requirements of teaching ethics and raises the issue of strategic support for educators in this area.

What was most surprising was the poor level of response to questions relating to the application of Fink’s learning theory. The questions looked to elicit details of the learning activities, instructional strategies and tools in use for the teaching of engineering ethics, both those actually used by the participants and those resources known to have potential use. At this stage, this will be interpreted to suggest four possible responses:

- the choice of Fink’s theory of significant learning did not resonate with engineering educators
- the educational jargon in which the questions were posed was inaccessible
- educators did not have the skill to engage reflectively with their own teaching methods
- educators did not value the questions or the process or have the time or inclination to engage with them.

Whilst the rationale for the project is not in question, the strategy of requiring participants to fill in a questionnaire gained limited traction from busy colleagues, despite the majority having a vested interest in improving the teaching of engineering ethics. The response rate of 57% and 22% of a target sample of educators, known personally and known to be interested in teaching ethics, demonstrated the challenge of eliciting interest from busy professionals. This was discouraging but also not unexpected as questionnaires are not an exciting methodological tool and were selected primarily for efficiency reasons as the short time line for the project necessitated a data collection tool that was manageable.

Although it would have been possible to choose to interview a smaller number of colleagues, this alternative was not selected as one of the driving concerns of the research was to involve a large cohort of engineering educators across institutions who would have the opportunity to respond and get involved in the research as collaborators.

Implications of the pilot research

The research project had clear objectives leading to potential outputs, including:

- a potential resource of tools and strategies for the teaching of ethics
- a strengthened sense of community built through the collaboration and
- a new conceptual framework for analysing the teaching of ethics within engineering.

One of the major challenges in formulating the research project was the recognition of the difficulty of motivating educators to be involved in a project that may not appear to be core to their daily operations. The identification of the community of engineering educators was identified as being a strategic element to assist in the process of encouraging collaboration around a transdisciplinary topic.

A further challenge involved how to proceed with a research project that aimed to involve engineering educators as co-researchers without prescribing how the research process would progress. The initial stage of the research aimed to generate interest and involvement and to enable the identification of potential collaborators for the project.

The next stage of the study requires refining of the conceptual framework and an expansion of the range of research participants in order to more comprehensively collate tools and strategies relating to the teaching of ethics to engineering undergraduate students in South African universities.
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University Dropout: A Prediction Model for an Engineering Program in Bogotá, Colombia

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Abstract: In Colombia, the desertion average rate shows that only around half of the students that begin an undergraduate program are finishing their studies. Although several models have been developed, the results of the implementation of strategies for student retention have not been sufficiently effective. Therefore, this study focuses on the creation of robust predictive models that allow timely anticipation of the risk that an engineering student will retire prematurely from the program. This phenomenon is analyzed in an empirical way through a methodology of Knowledge Discovery in Databases (KDD) using different machine learning techniques. Results show that the academic cost (in terms of the number of subjects viewed) and the semester the student entered have a significant impact on the probability of dropout occurring, especially when considering the dropout in the first semester. Then, acting on the students predicted by the model might reduce the number of dropouts.

Introduction
In the pursuit of growth and equity, no country can afford to ignore higher education. Through higher education, a country forms skilled labor and builds the capacity to generate knowledge and innovation, which in turn drives productivity and economic growth (Gitto, Minervini, & Monaco, 2016). Given that the acquisition of skills increases productivity and the expected income of people, a good education system is the basis for achieving greater equity and shared prosperity at the social level. Education allows us to update our potential, develop skills that allow us to be better (Patrick & Borrego, 2016).

However, the fact that a person abandons education has severe consequences. The event acquires greater relevance when occurs at higher education if you think about the preparation necessary to achieve this educational level. Furthermore, it is common to attribute the dropout to the failure of the student. A critical look at this position allows to notice that the problem is crossed by multiple factors; some are nested in the learning process itself, while others are alien to it and even out of their control (Lacave, Molina, & Cruz-Lemus, 2018).

In fact, in the Colombian context, one of the main problems the higher education system faces is the high levels of academic dropout from undergraduate programs. Although during the last five years have been characterized by increases in coverage and income of new students, the number of university students who complete their higher education is about 50%, suggesting that a large part drop out, mainly in the first semesters (Morales, Cordero, & Ramírez, 2017). According to statistics from the Ministry of Education of Colombia (2009), of
every hundred students who enter a higher education institution, nearly half do not complete their academic cycle and obtain graduation. Thus, knowledge of the factors that affect this phenomenon is the basis for developing effective policies in order to increase student retention (Esteban, Bernardo, Tuero, Cervero, & Casanova, 2017; Geisinger & Raman, 2013). Then, the measurement and study of student attrition should be part of the evaluation of the efficiency of the education system and of the quality of their processes.

Research in other countries provides evidence of a relationship between social or academic factors and the decision to leave the university without graduating (Munizaga, Cifuentes, & Beltrán, 2018). Likewise, (Fan & Wolters, 2014) suggest that explanations for student dropout without considering their motivation are incomplete. Official data from the United Kingdom indicate that dropping out of college is more likely for students from lower classes. Longitudinal studies conducted in the USA, using both national data and institutional data and differences in academic and social integration, resulted in different levels of institutional and educational commitment (Dicovskiy Ribóo & Pedroza Pacheco, 2018). However, the little research on high school dropout in Colombia opens a spectrum of possibilities to generate research. In fact, the few studies that have included, for example, social class in their investigation of the phenomenon of school dropout have found little evidence of class differences. In contrast, attrition decisions were more likely to be related to the averages of the high school aptitude tests with which the students entered university (Flórez-Nisperuza & Carrascal-Padilla, 2016; Torres Guevara, 2012).

**Research Question**

Given the background presented above, this study wants to explore the following research question:

- How can a university anticipate that a specific student is going to drop out from an engineering undergraduate program?

The purpose of this question is to develop a predictive model, based on four machine learning models and using a top layer model for the ensemble, to elucidate the social and academic factors that affect the student's decision to drop out from the Industrial Engineering program at Sergio Arboleda University. Even more, based on the model results, formulate strategies and institutional policies that increase student retention for engineer students. This model is important for engineering education because administrative staff and academic divisions could understand the relevant factors in the decision of dropout in engineer students and provide appropriate support to reduce dropout rates.

**Theoretical Framework**

**Student dropout models**

Among the researches carried out around the world, the Tinto model (1975) is the most accepted model in the literature on student retention in higher education. Tinto affirms that the students' decision to persist or drop out of their studies is strongly related to their degree of academic integration and social integration in the university. On the other hand, within the studies on student retention using quantitative tools, the classification algorithms (Kumar & Verma, 2012) are the most applied data mining technique to predict school dropout. A good example of the use of these methods is the research of Lykourentzou, Giannoukos, Nikolopoulos, Mpardis, & Loumos (2009), in which several classification techniques were applied (advanced neural networks, support vector machines (SVM), fuzzy schemes with probabilistic models and decision plans) for the prediction of dropout in e-learning courses at the University of Athens. The most successful technique to promptly and accurately predict the students who could defect was the decision plan. In other studies, for example, the authors used another comparative analysis of several classification methods (artificial neural networks, decision trees, SVM and logistic regression) to develop early models of freshmen...
who are more likely to drop out (Delen, 2010). However, current schemes have focused only on predicting using a single model, not parallel models, which is the objective of this study.

In Colombia, studies for follow-up, early diagnosis, and strategies for the prevention of student desertion are focused on survival analysis are the ones that have been used the most and with which the desertion models are created in the Colombia Ministry of Education (Ministerio de Educación Nacional, 2009). This type of dynamic models focuses on the study of this phenomenon according to survival functions, considering that the population is heterogeneous and assuming that the risk is equally probable for each person. This model also includes personal, academic, socioeconomic and institutional information, as suggested by Tinto’s models (Tinto, 1975). However, the results obtained, to the opinion of the authors, are vague and do not allow to capture the phenomenon entirely.

Methodology

As shown in the background, the traditional methodologies for predicting student dropout uses only the information from an academic background with single, classical and well-known classification algorithms. Therefore, we propose both a new methodology and the use of an ensemble model that attempts to produce better results and detect students’ dropout as early as possible. Three different models of student dropout were developed starting from the data gathered at different steps of the (Figure 1).

Figure 1: Proposed dropout prediction methodology.

As you can see in Figure 1, even at the beginning of the program, a premature dropout prediction can be made by using only the data available from personal and high school aptitude test (Saber 11) information about the student. As the program progresses, more information progressively becomes available about the performance of students. Therefore, two more models (early and late dropout) were developed to understand the phenomenon at different stages of the career.

Data Set

The dataset used in this study was built from the information of 422 students from the Industrial Engineering program from Sergio Arboleda University in the period 2016-2019. The main variable for examination on each one of the models is the dropout rate, which in the first model represents the students who did not obtain credits during their first semester, and the other models represent students who did not enroll by two or more consecutive semesters. The socioeconomic factors include social stratum, age, payment type (family resources, scholarships, or institutional agreements), and gender. About the academic performance, the data includes grade point average (GPA) each period, the number of lost courses and the average GPA before dropout. Furthermore, 23% of the students drop out, as you can see in Figure 2, being early dropout the most common case.
Data analysis

The models were built using the caret package of R©. The size of the training sets was 70% of the original dataset, according to the standard used by Microsoft (2018). Four models of classification were selected for the bottom level of the model: random forest, Bayesian classifier (using naïve Bayes), logistic regression, and neural networks. On the top level, a gradient boosting model was used, with the data of the previous models as input for the model.

Table 1: Confusion Matrix.

<table>
<thead>
<tr>
<th>Actual vs. predicted</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive</td>
<td>TP</td>
<td>FN</td>
</tr>
<tr>
<td>Negative</td>
<td>FP</td>
<td>TN</td>
</tr>
</tbody>
</table>

TP: True positive; FN: False negative; FP: False positive; TN: True negative

To compare the models, the chosen measures were specificity (equation 1), recall (equation 2), accuracy (equation 3), and AUC (equation 4), as suggested by Sokolova and Lapalme (2009), from the information obtained from the confusion matrix (Table 1).

\[
\text{Specificity}: \frac{TN}{TN+FP} \quad (1)
\]

\[
\text{Recall (Sensitivity)}: \frac{TP}{TP+FN} \quad (2)
\]

\[
\text{Accuracy}: \frac{TP+TN}{N} \quad (3)
\]

\[
\text{Area under the curve (AUC)}: \frac{1}{2} \left( \frac{TP}{TP+FN} + \frac{TN}{TN+FP} \right) \quad (4)
\]

All classification algorithms were executed using a 10-fold cross-validation procedure in which all executions are repeated 10 times using different train/test partitions of the data set. The data was validated to comply with the assumptions of each one of the individual classifiers, including independence between variables and considerations about the use of categorical variables.
Findings

Model 1: Premature dropout

In this model, the sample size is 422 students from an Industrial Engineering program. The variables used in this model were socio-economic variables (gender, rural or urban, type of funding, age, social stratum and type of admission) and the results of the high school aptitude test (Torres Guevara, 2012). The results of the four models and the two ensemble methods used are presented in table 2.

<table>
<thead>
<tr>
<th>Model</th>
<th>Specificity</th>
<th>Recall</th>
<th>Accuracy</th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naïve Bayes</td>
<td>0%</td>
<td>95.24%</td>
<td>95.24%</td>
<td>N/A</td>
</tr>
<tr>
<td>Logistic Regression</td>
<td>0%</td>
<td>95.24%</td>
<td>95.24%</td>
<td>N/A</td>
</tr>
<tr>
<td>Random Forest</td>
<td>0%</td>
<td>95.24%</td>
<td>95.24%</td>
<td>N/A</td>
</tr>
<tr>
<td>Neural Network</td>
<td>0%</td>
<td>95.24%</td>
<td>95.24%</td>
<td>N/A</td>
</tr>
<tr>
<td>Ensemble model (Voting)</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Ensemble model (Gradient boosting)</td>
<td>0%</td>
<td>95.24%</td>
<td>95.24%</td>
<td>N/A</td>
</tr>
</tbody>
</table>

These models, unfortunately, were not able to predict properly this kind of desertion. A possible explanation for this phenomenon is the high imbalance on the data (21 over 401) that makes difficult to predict. After checking the results, the four models only produce non-dropout results for everybody. This result suggests that, maybe, this kind of desertion is not significative to be considered.

Model 2: Early dropout

In this model, the sample size is 312 students from an Industrial Engineering program due to the only student on their third semester or higher were included. The variables used in this model were socio-economic variables (gender, rural or urban, type of funding, age, social stratum and type of admission), the number of subjects seen, the last available GPA, and the number of subjects lost. The results of the four models and the two ensemble methods used are presented in table 3.

<table>
<thead>
<tr>
<th>Model</th>
<th>Specificity</th>
<th>Recall</th>
<th>Accuracy</th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naïve Bayes</td>
<td>92.86%</td>
<td>93.67%</td>
<td>93.55%</td>
<td>93.26%</td>
</tr>
<tr>
<td>Logistic Regression</td>
<td>77.78%</td>
<td>94.67%</td>
<td>91.4%</td>
<td>86.22%</td>
</tr>
<tr>
<td>Random Forest</td>
<td>85.71%</td>
<td>100%</td>
<td>96.77%</td>
<td>92.86%</td>
</tr>
<tr>
<td>Neural Network</td>
<td>88.24%</td>
<td>96.05%</td>
<td>94.62%</td>
<td>92.14%</td>
</tr>
<tr>
<td>Ensemble model (Voting)</td>
<td>87.50%</td>
<td>96.81%</td>
<td>93.55%</td>
<td>91.55%</td>
</tr>
<tr>
<td>Ensemble model (Gradient boosting)</td>
<td>85.71%</td>
<td>100%</td>
<td>96.77%</td>
<td>92.86%</td>
</tr>
</tbody>
</table>
As we can see in the results, the four models were capable to produce accurate results that adjust properly to the data. In the level of the bottom models, we can appreciate that naïve Bayes and Random Forest outperform the Logistic Regression and the Neural Network, showing that they can be more specific and more accurate than the other models. In the top layer, both voting and gradient boosting were able to capture a higher performance that some of the models. However, the gradient boosting model shows better results by capturing the recall and accuracy of the random forest model.

**Model 3: Late dropout**

In the third model, the sample size is 158 students from an Industrial Engineering program due to the only student on their third semester or higher were included. The variables used in this model were socio-economic variables (gender, rural or urban, type of funding, age, social stratum and type of admission), the number of subjects seen, the last available GPA, and the number of subjects lost. The results of the four models and the two ensemble methods used are presented in table 4.

Table 4: Measures of performance for the late dropout model.

<table>
<thead>
<tr>
<th>Model</th>
<th>Specificity</th>
<th>Recall</th>
<th>Accuracy</th>
<th>AUC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Naïve Bayes</td>
<td>25%</td>
<td>92.86%</td>
<td>86.96%</td>
<td>58.93%</td>
</tr>
<tr>
<td>Logistic Regression</td>
<td>50%</td>
<td>95.24%</td>
<td>91.3%</td>
<td>72.62%</td>
</tr>
<tr>
<td>Random Forest</td>
<td>100%</td>
<td>93.33%</td>
<td>93.48%</td>
<td>96.67%</td>
</tr>
<tr>
<td>Neural Network</td>
<td>50%</td>
<td>95.24%</td>
<td>91.3%</td>
<td>72.62%</td>
</tr>
<tr>
<td>Ensemble model (voting)</td>
<td>100%</td>
<td>93.33%</td>
<td>93.48%</td>
<td>96.67%</td>
</tr>
<tr>
<td>Ensemble model (Gradient boosting)</td>
<td>N/A</td>
<td>91.3%</td>
<td>91.3%</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Finally, as shown in the previous table, there is a high variance between the model in terms of the specificity and the area under the curve (AUC). Specifically, the higher level on most of the parameters was reached by using the random forest technique. However, if we compare the models based on the sensitivity (or recall), both logistic regression and neural networks outperform the other models. In the top layer of the ensemble model, only the voting model was able to really capture the performance of the other models. The gradient boosting model was not even able to predict a single one case of late dropout.

**Discussion and Future Research**

Higher education dropout is being a big concern for academic institutions all over the world. The risk of student attrition has been studied broadly and deeply (Hällsten, 2017; Truta, Parv, & Topala, 2018; Vallejos & Steel, 2017), and the amount of data available about this phenomenon keeps growing every day. This data contains hidden knowledge about the features that could be used to predict the risk of the students to drop out in different moments of their studies. This paper proposes a student attrition model based on machine learning methods on different levels and using both social information and academic performance features. In general, the individual models and the ensemble models used by the authors produces good results in terms of the accuracy and AUC (more than 80% in model 2 and 3), which shows that the model strongly adjusts to the real data obtained. Compared with similar studies, this level of accuracy in the literature can be only found in Zhang’s study (2010), where using naïve Bayes models, 89% of accuracy was reached. However, due to access limitations to more complete data, our model can be improved to be more robust for the early detection of students who can drop out.
In terms of the use of the machine learning techniques, the key result from these models is that none of the individual methods used can be assured to be completely superior to the others. The objective of these models is to construct a discriminative classifier, which tries to approximate to the binary decision to drop out from an engineering program. Due to the size of the sample used in this study, the individual method can produce different results with different performance on each of the measurements checked, looking for local optima in the individual search strategy. Thus, using a combination of the classifiers with an ensemble method can provide better results by outperforming the individual searches and combining the outputs. In fact, ensemble machine learning has been used for several years for classification models, but their uses on the desertion of engineering students are relatively new because most of the models use a single learning approach (Amrieh, Hamtini, & Aljarah, 2016). From the results of the models, we can see that the use of gradient boosting method in the early dropout model, and the voting method for the late dropout model, let us obtain better capture the highest performance than using any individual model. These results support our hypothesis by showing that we can anticipate a certain pattern in our data to provide early alerts about students with a high risk of dropout. However, in this study, the cost in terms of computational time was ignored. The next step of this research will include a comparison of the models in terms of the costs associated with the performance level reached.

In terms of our results, even if our first model (premature dropout) does not provide enough information to anticipate if students will drop out before entering the program, our best estimation is every student will enter in the program and study at least one semester. Because of the little number of students who drop out prematurely (only 5%), this model can be improved by obtaining more information from other engineering programs. The second model, early dropout, and the third model, late dropout, reaches around 93% of accuracy on predicting drop out. A deep look in the model shows us that there are two features that help us predict desertion. First, the number of subjects seen by the students throughout their careers is a great predictor of non-dropout. In other words, when a student takes more subjects over time is less likely that wants to drop out. This is related to some theories that support that exist both a social and economic cost associated with the decision to drop out (Hällsten, 2017). Further research about the social, emotional and economic cost of dropping out will improve the results of this model. Second, there are differences between the groups of the students who start their studies in January (Group 1) than those who start their studies in July (group 2). Even this effect has not been completely understood by the authors, the model predicts more frequently than group 2 is more likely to drop out from an engineering program. This requires strategies to understand the differences between these groups and create policies to prevent the desertion. These two features, even more, will be studied by using more and complete data in future research.

References


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Motivational insights into students’ help-seeking behaviours in a resource-rich engineering course

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Abstract: Technology continues to increase the diversity of academic help resources available to college students, providing flexibility to create increasingly complex help-seeking patterns. This study examines the frequency of use across eight academic help resources available to students in an undergraduate mechanical engineering course, several of which are enabled by technology (e.g., videos, asynchronous discussion forum). We examine how students’ self-efficacy, perceived future value for their grade and their learning (i.e., instrumentality), and attitude toward educational technology influenced their help-seeking behaviours in addition to their prior performance, gender, and international student status. Our findings indicated that the frequency of help-seeking from face-to-face resources was not significantly predicted by motivational and attitudinal characteristics; these characteristics significantly predicted how frequently students sought help from mediated resources. International students used formal audio/video resources more frequently and formal text-based resources less frequently than domestic students, which aligns with findings in a related study where international students cite audio/video resources as particularly beneficial for mitigating any language barrier in the classroom.

Introduction

Help-seeking behaviours with technology

Technology is transforming engineering education in many ways, one of which is providing new avenues for students to seek academic help. The increasing diversity of resources enabled by technology provides flexibility for students to follow multiple and increasingly complex help-seeking patterns. Factors that influence students’ decisions to seek help from academic resources have been extensively researched from a motivational perspective (Karabenick & Knapp, 1991); however, new educational technologies open questions into how students navigate resource-rich and technology-enabled learning environments (Makara & Karabenick, 2013). This study investigates how students’ help-seeking patterns in a mechanical engineering course are related to their personal and attitudinal characteristics for eight different resources, three of which are technology-enabled. With this information, we hope to better understand the strengths and weaknesses of each resource as perceived by students which can inform adaptation to other educational contexts and emphasize the importance of a variety of resources to meet individual student needs and preferences.
Context for this study
This study explores students’ academic help-seeking behaviours in an undergraduate mechanical engineering (ME) course (Dynamics) at Purdue University in the Midwest of the United States. The course employs a rich set of academic help resources (Rhoads, Nauman, Holloway, Krousgrill, 2014) and is structured around a lecturebook—a combination of textbook information and practice example problems with space for students to work and take notes (Krousgrill & Rhoads, 2016). There is also a course website which contains narrated step-by-step solution videos to all calculation problems in the lecturebook (hereafter referred to as ‘lecture example videos’). The website also has a discussion blog where students primarily seek and provide help on homework problems. Instructors hold office hours and teaching assistants (TAs) are available in open-use tutorial rooms throughout the week. Students are known to collaborate with peers face-to-face in these tutorial rooms, in their own spaces, and through personal digital communications, e.g., WhatsApp or GroupMe.

Our prior research, which encompasses all ME students at Purdue University (Wirtz, Dunford, Berger, Briody, Guruprasad, Senkpei, 2018), shows that students tend to use convenient resources, like the lecturebook and website, more frequently than those with restricted accessibility such as office hours. ME students perceived their peers to be their most useful academic help resource and they described an overall collaborative help-seeking culture in ME at Purdue University. Students also reported that they perceive online course materials to be more useful than a textbook and tended to use those online resources more. Knowing general help-seeking patterns, we now aim to explore personal and attitudinal factors that influence these behaviours across a variety of resources available in one course.

Literature Review
Self-efficacy
One of the primary motivational influences on a student’s decision to seek help is a judgement of their ability to complete the task for which they need help, i.e., their self-efficacy (Zimmerman, Bandura, Martinez-Pons, 1992). Students with high self-efficacy in a particular domain tend to show increased academic effort, persistence, and performance on related tasks (Credé & Phillips, 2011). In contrast, students with low self-efficacy may fear embarrassment or asking a rudimentary or ‘stupid’ question, and may therefore avoid some resources such as an instructor’s help in class or during office hours (Karabenick, 2003). Low self-efficacy is generally related to less effective learning strategies such as avoidance of help-seeking (Ryan, Pintrich, Midgley, 2001).

Perceived instrumentality
Students’ help-seeking behaviours are also influenced by their future goals (Zusho, Karabenick, Bonne, Sims, 2007) and how a present task for which they need help is related to those goals (Raynor, 1981). Students who value learning course content because it is directly related to achieving their future goals are said to perceive endogenous instrumentality, which has been associated with positive outcomes for help-seeking and academic performance (Hilpert, Husman, Stump, Kim, Chung, Duggan, 2012; Kim, 2016). At the same time, students may also perceive value their course grade as a necessary hurdle toward achieving future goals, called exogenous instrumentality. Overall, self-efficacy and both types of perceived instrumentality support positive academic outcomes; however, having low self-efficacy and high instrumentality, i.e., placing high value on a task with low confidence in one’s ability to complete the task, can have a negative impact on academic performance (Kim, 2016). Endogenous instrumentality tends to be more effective than exogenous instrumentality in promoting positive learning behaviours (Nelson, Shell, Husman, Fishman, Soh, 2015) and performance (Kim, 2016).
Attitude toward educational technology

Students’ attitudes toward affordances and drawbacks of educational technology influence their preferences for technology-enabled help resources. Generally, a positive attitude toward educational technology increases the perceived value of those help resources and promotes their usage (Mitra & Steffensmeier, 2000).

Framework for technology-enabled help resources

Makara and Karabenick (2013) present a four-dimensional framework which can be used to describe traditional and technology-enabled academic resources. The framework uses dimensions that are salient to students’ self-efficacy, instrumentality, and attitude toward educational technology. These dimensions (italicized for emphasis below) can be used to discuss potential reasons behind students’ decisions to seek help from one resource or another, or not at all.

The role of a resource, i.e., the formality, is typically established through authority or designation as a trustworthy source of information (e.g., instructor, lecturebook). College students are more likely to use formal resources when they are motivated to learn the material (Karabenick, 2001) and have high academic self-efficacy (Kitsantas & Chow, 2007). Prior educational experience and cultural norms may also lead to different tendencies for help-seeking from formal resources such as the instructor (Hillis, 2017).

The relationship between student and help resource can range from being personal (e.g., peers) to impersonal (e.g., lecturebook). The perception of relationship for technology-enabled resources (e.g., course blog, narrated videos) may depend on factors such as class size and students’ attitude toward educational technology.

The channel through which help is sought can be either face-to-face or mediated. Mediated resources are those which use text, audio, and/or video to communicate information. Some students prefer face-to-face help-seeking while others prefer to use mediated resources before face-to-face help resources, often citing convenience (Wirtz et al., 2018) or perceived threats (Reeves & Sperling, 2015).

The adaptability of a help resource describes whether information is static or dynamic, i.e., tailored specifically to the help-seeking need. Our prior research found that students in ME tended to use mediated, static resources first (most accessible), before reaching out to peers who can provide informal dynamic help; peers were perceived as the most useful help resource, even more than instructors and TAs (Wirtz et al., 2018).

Research question

While we do have a sense of what students’ help-seeking behaviours look like and what motivates these decisions from prior research (Makara & Karabenick, 2013; Wirtz et al., 2018), the growing abundance of resources in a technology-enhanced learning environment makes understanding these decisions more complex.

The research question posed in this paper is: To what extent are students’ help-seeking behaviours in a resource-rich, technology-enhanced course predicted by their motivations and attitude toward educational technology, and are they dependent on personal characteristics of gender or international student status?

Methods

Sample population

The sampling frame for our data collection comprised two academic years of students enrolled in Dynamics (4 semesters, summer not included), totalling 983 students. The student-to-faculty ratio is about 50:1 during the first semester (August – December) and about 90:1 during the second semester (January – April). The summer term (May – July) is
significantly compressed and there is much lower enrolment, leading to remarkably different help-seeking behaviours.

Only those students who completed both rounds of data collection (discussed below) were included in this study, comprising 469 students of the total enrolled population (47.7%). International students make up 18.6% of the sample population, which is less than the international student population in engineering at Purdue University (32%) or in the ME department (40%). The representation of women in the sample population (25%) is similar to the engineering undergraduate population (24%) and higher than in the ME department (15%). There are relatively few students from under-represented minority (URM) groups in the course, limiting statistical investigations.

Data collection

During the first week of the semester, participants completed our consent form and an attitudinal survey which were approved by the research ethics board at Purdue University. The survey comprised 31 questions about self-efficacy (Pintrich, Smith, Garcia, McKeachie, 1991), endogenous and exogenous instrumentality (Hilpert et al., 2012), and attitude toward educational technology, all which used a 7-pt Likert scale from (1) Strongly Disagree to (7) Strongly Agree.

We contacted students via email at the end of the semester with a second survey using Qualtrics, an online survey tool, to gather information about their help-seeking behaviours during the course. Students reported the frequency with which they used each help resource (listed in Table 1) on a 6-pt scale that was centred on a weekly frequency to align with students’ typical class schedule period: (1) never, (2) 1-3 times per semester, (3) 1-3 times per month, (4) 1-2 times per week, (5) 3-6 times per week, (6) daily.

Table 1: Help resources, classified using multi-dimensional framework (Makara & Karabenick, 2013).

<table>
<thead>
<tr>
<th>Help resource</th>
<th>Role</th>
<th>Relationship</th>
<th>Channel</th>
<th>Adaptability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lecturebook</td>
<td>Formal</td>
<td>Impersonal</td>
<td>Mediated</td>
<td>Static</td>
</tr>
<tr>
<td>Lecture example videos</td>
<td>Formal</td>
<td>Impersonal</td>
<td>Mediated</td>
<td>Static</td>
</tr>
<tr>
<td>Peers</td>
<td>Informal</td>
<td>Personal</td>
<td>F2F/Med</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Course Blog</td>
<td>Informal</td>
<td>Im/Personal</td>
<td>Mediated</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Other online help sources</td>
<td>Informal</td>
<td>Impersonal</td>
<td>Mediated</td>
<td>Static</td>
</tr>
<tr>
<td>Questions in class</td>
<td>Formal</td>
<td>Personal</td>
<td>Face-to-face</td>
<td>Dynamic</td>
</tr>
<tr>
<td>TAs in tutorial rooms</td>
<td>Formal</td>
<td>Personal</td>
<td>Face-to-face</td>
<td>Dynamic</td>
</tr>
<tr>
<td>Instructor’s office hours</td>
<td>Formal</td>
<td>Personal</td>
<td>Face-to-face</td>
<td>Dynamic</td>
</tr>
</tbody>
</table>

Table 1 describes the eight help resources in this study using Makara and Karabenick’s (2013) help resources classification framework. The resources are classified using dichotomies, although Makara and Karabenick (2013) emphasize that students make their own judgements for each dimension of each help resource. For instance, students may seek help from peers in a face-to-face setting or via digital communication.

Quantitative data analysis

We used a set of eight separate linear multiple regression analyses to investigate how students’ demographic, motivational, and attitudinal characteristics predicted the frequency of their help-seeking behaviours from each help resource.

Each regression model used the same set of eight independent variables to predict reported frequency of use. The demographic variables (gender, international student status) were binary independent variables. The motivational variables (SE, EN, EX) and attitudinal variables (ICT+, ICT-) were continuous independent variables (scale: 1.0 – 7.0) that were calculated by taking the average of the associated sub-scale items. Prior performance in the
pre-requisite statics course was measured by a letter grade represented on a 4.0-scale. Figure 1 visually represents the multiple regression model and classifies the independent variables as either personal characteristics or attitudinal characteristics (Pintrich & Zusho, 2007). Standardized regression coefficients (beta, \( \beta \)) are reported with statistical significance indicated for \( p \leq 0.050 \).

Figure 1: Model used for multiple linear regression of each help resource

The first (attitudinal) survey had 1.21% missing data, replaced by the average of other items from the same theoretical construct for each particular student. The second (help-seeking behaviour) survey had 0.11% missing data, replaced by the average of the population (Downey & King, 1998). While the independent and dependent regression variables were not all normally distributed, the assumption of normally distributed regression residuals was examined for each regression model. Violation of the normality assumption by independent and dependent variables reduces the reliability of the analyses; however, our study greatly exceeds 10 observations per variable, making it more robust to this violation (Osborne & Waters, 2002). Multi-collinearity was investigated through pairwise correlations among independent variables which were well below the \( r = 0.70 \) rule-of-thumb (Dormann et al., 2012).

Findings

To examine the factors that influence students help-seeking behaviours across different types of help resources, we conducted a set of multiple regression analyses using demographic, motivational, and attitudinal characteristics as independent variables. The regression results are preceded by descriptive statistics and correlations among independent continuous variables to inform interpretation of the regression results.

Table 2: Descriptive statistics of students’ help-seeking behaviours, listed in descending order by frequency of use. (6 = daily use, 1 = never used)

<table>
<thead>
<tr>
<th>Help resource</th>
<th>Mean (SD)</th>
<th>Skewness</th>
<th>Kurtosis</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Lecturebook</td>
<td>4.78 (1.02)</td>
<td>-1.775</td>
<td>4.435</td>
</tr>
<tr>
<td>2. Peers</td>
<td>4.24 (1.23)</td>
<td>-0.885</td>
<td>0.302</td>
</tr>
<tr>
<td>3. Lecture example videos</td>
<td>4.23 (1.05)</td>
<td>-0.892</td>
<td>0.776</td>
</tr>
<tr>
<td>4. Course blog</td>
<td>3.71 (1.47)</td>
<td>-0.543</td>
<td>-0.852</td>
</tr>
<tr>
<td>5. Other online sources</td>
<td>2.64 (1.48)</td>
<td>0.489</td>
<td>-0.890</td>
</tr>
<tr>
<td>6. Questions in class</td>
<td>2.43 (1.29)</td>
<td>0.543</td>
<td>-0.634</td>
</tr>
<tr>
<td>7. Tutorial rooms</td>
<td>2.49 (1.62)</td>
<td>0.596</td>
<td>-1.179</td>
</tr>
<tr>
<td>8. Office hours</td>
<td>1.71 (1.01)</td>
<td>1.593</td>
<td>2.345</td>
</tr>
</tbody>
</table>

The lecturebook was the most frequently used resource, with over 90% of students indicating that they used it more than once per week. The lecture example videos, which directly supplement the lecturebook, also tended to be used more than once per week. These are both static and formal resources that are easily accessible for students. Peers were also
consulted more than once per week which was expected given the collaborative nature of the course (Zadoks et al., 2017) and the ME department (Wirtz et al., 2018). Students also reported using the course blog approximately once per week, which may indicate reading or voting on others’ posts, making a post, or replying to another post. Students generally reported using formal and face-to-face help resources the least (resources 6 – 8).

Table 3: Pearson’s correlation coefficients between continuous independent variables used in linear multiple regression. p < 0.050 (*), p < 0.010 (**), p < 0.001(***)

<table>
<thead>
<tr>
<th></th>
<th>SE</th>
<th>EN</th>
<th>EX</th>
<th>ICT+</th>
<th>ICT-</th>
</tr>
</thead>
<tbody>
<tr>
<td>Statics Grade</td>
<td>0.344***</td>
<td>0.161***</td>
<td>-0.033</td>
<td>-0.026</td>
<td>-0.010</td>
</tr>
<tr>
<td>Self-efficacy (SE)</td>
<td>---</td>
<td>0.329***</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Endogenous instrumentality (EN)</td>
<td>-0.011***</td>
<td>0.328***</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Exogenous instrumentality (EX)</td>
<td>0.132**</td>
<td>0.298***</td>
<td>0.110**</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>Positive Educational Technology Attitude (ICT+)</td>
<td>-0.084*</td>
<td>-0.228***</td>
<td>-0.114***</td>
<td>-0.282***</td>
<td>---</td>
</tr>
<tr>
<td>Negative Educational Technology Attitude (ICT-)</td>
<td>*</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td>***</td>
</tr>
</tbody>
</table>

Table 3 shows the correlations between the motivational and attitudinal independent variables. There were moderate correlations (r > 0.30) between self-efficacy (SE) and endogenous instrumentality (EN), and separately between exogenous instrumentality (EX) and EN; however, SE and EX do not appear related. This suggests that students who have high self-efficacy tend see high future value for the content, but not necessarily for their grade. Students’ self-efficacy and both instrumentality values are related to a positive attitude toward educational technology. In contrast, those students who view educational technology negatively tended to have lower value for the course content and their grade.

Usage of mediated help resources

Table 4 shows the standardized regression coefficients (β) which capture the extent to which students’ help-seeking behaviours from mediated help resources were predicted by their personal and attitudinal characteristics. International students reported using the lecturebook significantly less frequently than domestic students (β = -0.098) while using the lecture example videos and other online resources significantly more frequently than domestic students (β = 0.093 and β = 0.112, respectively). In addition, women generally reported using the lecturebook significantly more frequently than men (β = 0.115). This opens questions into how the unique format of the lecturebook—a hybrid of textbook and workbook—is perceived by students with different backgrounds and whether there are other online resources that international students find useful. In a related study (Kandakatla, Berger, Rhoads, DeBoer, 2019), international students’ interview data indicated that lecture example videos are useful for reviewing content after class which may have been obscured by a language barrier.

Although prior performance in statics, self-efficacy, and endogenous instrumentality are all significantly and positively correlated (see Table 3), they predicted significantly different use of the mediated resources. Students with high SE tended to rely on the lecturebook less frequently (β = -0.143) while students with high EN used it more frequently (β = 0.202). This suggests that confident students do not feel the need to revisit material as frequently, whereas students who place a high value on their learning view the lecturebook as a valuable help resource. In addition, students with high EN tended to use the course blog more frequently (β = 0.127), with no apparent influence from prior performance in statics or SE. It may be that students who value learning the content are more inclined to read or participate on the course blog because the discussions are often conceptual in nature, capture the difficult aspects of the material, and provide opportunities for peer-learning, all of which can contribute to deeper understanding of the material (Perkins, 2009).
A positive attitude toward educational technology positively predicted the use of lecture example videos and the course blog, the two technology-enabled resources provided through the course ($\beta = 0.159$ and $\beta = 0.139$, respectively). It appears that students who are more receptive to educational technology are more likely to utilise it regularly when provided through the course and are no more likely to seek other online resources.

**Usage of face-to-face help sources**

Students use *face-to-face* and *formal* resources least frequently of all the resources surveyed (see Table 2), and there are fewer significant predictors of the face-to-face help resource multiple regression models, shown in Table 5. The motivational and attitudinal characteristics did not significantly predict use of any *face-to-face* help resources and the full regression model explained very little of the usage of peers ($R^2 = 0.036$) or tutorial rooms ($R^2 = 0.043$) as help resources.

**Table 5: Multiple regression analyses predicting frequency of use from face-to-face help resources. Each help source used an individual multiple regression analysis.**

<table>
<thead>
<tr>
<th></th>
<th>Statics</th>
<th>International</th>
<th>Gender</th>
<th>SE</th>
<th>EN</th>
<th>EX</th>
<th>ICT+</th>
<th>ICT-</th>
<th>Model R²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peers</td>
<td>-0.116</td>
<td>-0.069</td>
<td>0.020</td>
<td>0.063</td>
<td>0.083</td>
<td>-0.014</td>
<td>-0.014</td>
<td>-0.011</td>
<td>0.036</td>
</tr>
<tr>
<td>Questions in class</td>
<td>-0.058</td>
<td>0.089</td>
<td>-0.181</td>
<td>0.096</td>
<td>0.184</td>
<td>-0.001</td>
<td>0.033</td>
<td>-0.043</td>
<td>0.102</td>
</tr>
<tr>
<td>Tutorial rooms †</td>
<td>-0.062</td>
<td>0.076</td>
<td>0.071</td>
<td>-0.013</td>
<td>-0.051</td>
<td>-0.044</td>
<td>0.044</td>
<td>0.089</td>
<td>0.043</td>
</tr>
<tr>
<td>Instructor office hours</td>
<td>-0.144</td>
<td>0.193</td>
<td>-0.065</td>
<td>0.054</td>
<td>0.037</td>
<td>-0.049</td>
<td>0.088</td>
<td>0.039</td>
<td>0.084</td>
</tr>
</tbody>
</table>

† The regression residuals appeared more bimodal than normal in distribution, limiting validity of this analysis.

Students who did well in the pre-requisite statics course tended to access *face-to-face* resources less frequently. It may be that the students who performed well in statics (which employs a similar set of resources) learn sufficiently well from the available *mediated* help resources discussed previously and do not need to access these less convenient resources. International students reported a significantly higher frequency of using instructor’s office hours ($\beta = 0.193$). However, the instructor’s office hours are used very infrequently overall (see Table 1) so this result may be indicative of international students using instructor office hours only a few more times than domestic students. In addition, women showed a significantly lower tendency of asking questions of the instructor in class ($\beta = -0.181$), which aligns with prior findings in other large undergraduate science courses (Eddy, Brownell, Wenderoth, 2014).
Implications for Engineering Education Practice

This study sheds light on personal and attitudinal characteristics of students that influence their help-seeking behaviours, particularly from mediated help sources such as those enabled through educational technology (e.g., videos, discussion blog).

Supporting language learners through help resources

The Dynamics course uses active, blended, and collaborative pedagogical approaches which increase activity and collaboration in the classroom (Zadoks et al., 2017) and flexibility for learning outside of the classroom (Rhoads et al., 2014). While collaborative learning generally promotes deeper learning than working individually (Chi & Wylie, 2014), international students have discussed how this in-class learning environment increases apprehension because they are English-language learners (Kandakatla et al., 2019). These international students cited the lecture example videos as a supplementary help resource that allows them to review class content at their own pace. In a similar sense, instructors’ office hours offer an environment in which communication of questions and ideas may be easier with less surrounding activity than during class.

While technology may be beneficial, it has limits

The adoption of technology-enabled help resources is itself a resource-intensive endeavour. One aim of this research was to consider the characteristics of these help resources that are transferrable to other contexts by employing Makara and Karabenick’s (2013) framework. For instance, we found that resources that are vetted by instructors and specifically provided to students are the most frequently used. An instructor’s references to online help resources, whether developed specifically for the course (e.g., course blog) or publicly available (e.g., YouTube), provide avenues for all students to feel that the material is trustworthy.

Another limitation to adopting help resources like the course blog, specifically in engineering science courses, may be due to the mathematical and graphical nature of content that is not easily communicated using text. We found that students who were receptive to affordances of educational technology used the technology-enabled help sources more frequently. Because our students generally have prior exposure to similar educational technology and help resources in Statics, they may be more inclined to use it with advanced content in Dynamics. It is worthwhile to consider the receptivity of learners to educational technology and to gradually introduce new technologies into the learning environment.

Limitations

Some of the data involved in this study were not normally distributed (see Table 1) which can lead to reduced reliability of the results. Employing curvilinear analysis or moderation analysis may illuminate more nuanced relationships among the variables that the present multiple regression analyses did not capture. Students’ recollection of study habits across the semester may have self-report bias and the variety in help resources such as peers or other online sources may introduce interpretation bias because we do not know the details of those help resources.

Future work

The findings presented in this study open several areas for future inquiry within our context and across diverse engineering education contexts. The next steps of the present analysis are to expand the model to predict academic performance from the present characteristics help-seeking behaviours and incorporate moderation effects. In addition, we hope to understand how similar resources, such as solution videos and discussion blogs, are employed in other engineering science courses and other contexts.
Conclusion

This study has revealed insights into students’ help-seeking patterns across a suite of help resources, several of which are technology-enabled. Students continue to use convenient help resources more frequently, and their usage appears significantly influenced by students’ personal and motivational characteristics. One major finding is that the help resources for which communication is more easily controlled (e.g., lecture example videos or instructor office hours) may be particularly valuable to students who do not speak the primary language used in the classroom. In addition, our findings suggest that students’ motivational characteristics are more influential in their decisions to seek help from mediated help resources compared to face-to-face resources. We look forward to more research which compares perceptions and use of technology-enabled help resources from a motivational perspective across global contexts.

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Assisting tutors to develop their student’s competence when working with complexity.

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Abstract: Practising engineers are required to be independent learners, using their judgement and creativity to arrive at solutions to complex real-world problems. Research reports that these skills are currently underdeveloped in engineering students. This is not surprising given that most engineering students have undertaken mainly science and maths subjects in which they apply their mathematical knowledge to arrive at unique solutions. Conversely, in engineering practice, activities are rarely characterised by an ideal answer but rather are complex, requiring trade-offs and combining non-optimum solutions. Dealing with complex problems requires students to use judgement, subjectivity, and reasoning to make decisions instead of relying solely on the scientific evidence and facts. This challenges many students’ feeling of competence and inhibits their learning motivation. In this paper, we report introducing student tutors to self-determination theory and a framework to provide a context and vocabulary to understand, reflect on and discuss learning when managing complexity to improve their students’ learning and feelings of competence.

Introduction

Authentic engineering projects are complex in that they require engineers to use judgement, managing multiple possibilities, competing demands and having to make assumptions to develop considered and reasoned solutions. These solutions often have remaining uncertainty that may only be resolved, if at all, in retrospect after implementation. Brookfield reports that learning that challenges and stretches students, asks them to think critically or use their judgement to deal with uncertainty and complexity, often induces resistance (Brookfield 2017).

In previous studies (Willey and Machet 2018, Willey and Gardner 2014a, 2014b) we found that when students were introduced to open-ended, multidiscipline projects, many students welcomed the opportunity:

“The project felt very real-world and it was very helpful that it was a real scenario from a real company, and something so different from anything we’ve done before…”,

while others called for change describing the projects as too difficult, too much work, less valuable and not real engineering:

“Whilst the project was very open-ended, there were details that felt just a too vague and general which was hard because it meant that there wasn’t a good sense of limits or expectations”.

[The project should be] “more technical and mathematics”.

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Viewing the student feedback through the lens of self-determination theory (Ryan and Deci, 2000) we theorised that many students resist dealing with complexity because they do not feel competent nor understand the learning processes (which may be quite different from their previous experience). Dealing with complexity requires students to use judgement, subjectivity, and reasoning to make decisions instead of relying primarily on the scientific evidence and facts. Many engineering students expect their learning to be the simple transition from the ‘knowable’ to the ‘known’ (Kurtz and Snowden, 2003), finding it difficult to think contextually and dialectically to find approaches to engineering problems. Reduced feelings of competence, inhibits students' learning motivation and their interest in addressing and benefiting from complex learning activities.

In the flipped classroom, learning can be described as a co-constructed partnership between tutors and students. Hence, for successful learning tutors need to find ways to articulate and scaffold students’ learning experiences and their learning expectations. Students need a learning language to engage with the expected learning outcomes and judge their competency in meeting these outcomes.

In Willey and Machet (2018) we introduced a learning framework and language evolved from the Cynefin Framework. It was developed for tutors, to scaffold, articulate and model learning methods and expectations to students, provide students with a language to discuss, evaluate their competence and understand their learning, and to allow tutors and students to co-construct the learning outcomes and expected academic standards when managing complexity.

In flipped classrooms and tutorials it is often only the tutors that have face-to-face contact with the students. Hence, they are often responsible for scaffolding students’ understanding and skill development to manage complexity. Thus it is important for tutors to feel comfortable explaining working with complexity and to see their role as facilitating learning rather than simply providing solutions to and or clarifying student's questions. To facilitate this we hold tutor training workshops that include tutors being introduced to self-determination theory and the complexity framework explained later in this paper. Tutors are asked to reflect on their approach to tutoring and are engaged in discussions to provide a context to understand how the students may behave and respond to learning that involves managing complexity.

In this paper, we investigate tutor's reactions to the framework, language and learning theories and how useful they believe they will be in assisting them to improve their understanding of, or interactions with, students in their tutorials and how they might use these tools to improve their student's learning.

Self-determination Theory

Self-Determination Theory links personality and motivation in an effort to describe human behaviour and the choices we make. Built on research about motivation, differentiating between intrinsic motivation (a self-desire to seek out new challenges) and extrinsic motivation (influence from outside forces), Self-Determination Theory describes a continuum from amotivation, “the state of lacking the intention to act”, through extrinsically motivated action, to fully intrinsically motivated and self regulated behaviour (Ryan and Deci, 2000a). The theory is built on the belief that humans have an inherent propensity to learn and develop and describes that in order to be motivated to achieve their potential growth, a person’s basic cognitive needs of autonomy, competence and relatedness must be met.

Self-determination theory has significant application in the education domain where Ryan and Deci (2000b) identify that supporting these three basic needs in the classroom facilitates students’ natural inclination for learning and well being. That is, students need to feel they have some control over their learning and outcomes (autonomy), that they are able to master
the learning content (competence) and to feel a sense of connectedness to others within the context (relatedness), in order to be motivated to learn and grow through the experience. Inhibiting any of these basic needs reduces students’ motivation and inhibits learning.

We believe that many students have difficulty with learning tasks that deal with complexity and this lack of competency results in reduced motivation and resistance to learning in these scenarios.

**Cynefin Framework**

The Cynefin framework was developed to help people make sense of the complexities in knowledge and organisational management (Kurtz and Snowden, 2003 p468). It is designed to help people break out of old ways of thinking and to consider intractable problems in new ways by providing constructs that can be used to make sense of a wide range of problems.

The framework offers four decision-making contexts or domains, each offering a perspective from which to analyse behaviour and make decisions. The domains were originally designated:

1. **Known**: cause-and-effect relationships repeatable, perceivable and predictable
2. **Knowable**: cause-and-effect separated over time and space
3. **Complex**: cause-and-effect are only coherent in retrospect and do not repeat
4. **Chaos**: no cause-and-effect relationship perceivable

The fifth or central domain between the other four domains is called the domain of disorder.

The Known and Knowable domains are those of order, while the Complex and Chaos domains represent un-order.

**Engineering Complexity Framework**

The Cynefin framework concepts are useful and provide an additional perspective for us to better understand our student’s resistance to dealing with complex problems. To assist scaffolding and for both tutors and students to be able to relate the concepts of the Cynefin framework to their experience, we decided to adapt the language, context and visualisation to our engineering context. We developed (through several iterations and discussions with both tutors and students) a simple framework that differentiates between learning absolutes and learning with complexity.

The aim of this framework design is to:

- Provide a vocabulary to understand, reflect on and discuss learning when managing complexity in order to improve students’ feelings of competence and their capacity to evaluate their competence.
- Use these improved feelings of competence to reduce learner resistance, improve motivation and thereby improve student’s learning and their learning experience.
- Enable tutors to build a case for, and students to value, learning to manage complexity and view it as a legitimate and important part of professional practice.
- Enable tutors and students to co-construct their learning environment.

The proposed framework (Figure 1) differentiates between ‘learning absolutes’ (right hand side, RHS) and ‘learning with complexity’ (left hand side, LHS). The framework reflects how engineering students’ learning is often associated with absolutes, moving from the ‘knowable’ to the ‘known’ using predetermined rules, facts and analysis to manage encountered uncertainty (RHS Figure 1a). After learning, both knowledge and competence are attained (Known) (RHS Figure 1b).
Figure 1: Pre-and post-learning objectives and transition paths when learning absolutes and managing complexity (Willey and Machet, 2018)

The methods and techniques used in the ‘known and knowable’ domains do not work when managing complexity and you can’t move from a truly complex problem to a known solution. Engineering practice involves complex problems and the solutions require the use of judgement, subjectivity, the management of multiple possibilities, competing demands and having to make assumptions to develop considered and reasoned solutions to complex problems (LHS Figure 1a). To resolve uncertainty, theories and assumptions are probed and tested, feedback is evaluated and then a course of action can be chosen. The resulting solution (LHS Figure 1b) will contain residual uncertainty that may only be resolved, if at all, in retrospect after implementation.

Methodology

The Faculty of Engineering and Information Technologies at the University of Sydney, hold a mandatory tutor training workshop for all new tutors. Most of the tutors are undergraduate students, tutoring in a subject they have previously undertaken. A small number are postgraduate students.

In the workshop, tutors are introduced to learning theories such as constructionism, affective processes including self-efficacy and agency, and the different stages of reflection and its role in learning. These concepts provide background to understand and reflect on how their students behave and respond to different learning activities and to assist them in scaffolding these activities to their students.
Within the training workshop, tutors are introduced to self-determination theory (SDT). They are asked to use SDT to evaluate their tutorial learning activities. In particular, to identify how their tutorial activities provided opportunities for students to exercise autonomy, include the social dimensions of learning through group and/or collaborative activities and to consider that resistance or pushback to their tutorial learning activities may result from students not feeling competent to undertake the associated tasks.

The complexity framework and supporting language are then introduced to tutors, including a description of how the framework explicitly describes the way many students have previously experienced and/or approached their learning, expecting it to be a simple transition from the knowable to the known, and how these methods cannot work when dealing with complex open ended problems. Complex problems require students to manage uncertainty through using judgement, subjectivity, and reasoning to make decisions, instead of relying primarily on scientific evidence and facts.

In the workshops, it was explained that the framework and language were introduced for tutors to share with their students in order for the students to understand that it is normal to be uncertain when dealing with a complex problem, and that learning how to manage complexity is an explicit learning outcome of such activities. Tutors are asked to think of examples of when they as a student have experienced, or have observed in another student, resistance to a learning activity or assessment. They were asked to reflect and share with those sitting around them whether they could relate this resistance to not feeling competent and/or with the uncertainty associated with dealing with a complex problem. The subsequent workshop discussions were used to explore a number of scenarios and use self-determination theory and the complexity framework as a lens through which to examine what was occurring.

After the workshop, tutors were surveyed to ascertain whether they found the concepts of Self Determination Theory and the complexity framework and language useful and to briefly describe if they thought they would help them to improve their understanding of, or interactions with, students in their tutorial class and how they might use them to improve their student's learning.

**Results & Discussion**

The responses from the 18 tutors (invited cohort 158) who completed all survey questions were used in the following analysis.

**Self-determination theory**

In the workshops self-determination theory (identifying competence, autonomy, and relatedness as basic cognitive needs for motivation) was introduced and tutors were asked to use the theory to examine the way they facilitated their tutorials and in particular, think about student resistance as stemming from them not feeling competent to engage with or undertake an activity. The tutors were surveyed on their thoughts as to the usefulness and possible application of the theory to their own classes.

All the responses indicated that tutors believed the theory to be helpful, with some indicating that they were aware of it before the training.

“I’ve encountered this theory before when studying skill acquisition in a previous degree. I think this is a useful framework to remind us how to keep our lessons as valuable to the students and to be alert for how quickly a student can disengage if they feel completely lost. By this framework tutoring is a balance of ensuring the students feel competency without taking over their autonomy, which I think is a fair consideration”.

“This was a very useful concept to introduce into my perception of teaching, as it encompasses many facets of learning that I had passively understood but not brought
to words. It outlined for me the importance of self-autonomy & competence [sic] for students, allowing me to reflect on my own teaching methodologies going forward”.

A number of tutors showed that reflecting on the theory had an impact on how they intended to facilitate their tutorials.

“I found it extremely intriguing and I can see the benefits of the concept being brought to our attention. Remembering that students may feel a sense of incompetency when I'm tutoring, I will ensure that we cover basic concepts first when addressing an issue a student has encountered.”

“...students so far have been used to high school teachers mostly spoon feeding them on what they need to know and study for. As a result students may expect the same from their lecturers and tutors. I suppose tutors can help smooth students into this transition, such as letting the students solve questions in groups and can make harder questions much less intimidating”.

“I think this concept is fairly intuitive, from my experience I find that tutors often misuse their knowledge of this concept and don't use effective methods to enable their students to be competent, autonomous or to understand the relevance of what they are learning. For example, there is a difference between steering a student towards the resources available to them, or explaining that you want them to learn how to find and research answers, and instead saying "you can work it out, or google is your friend" both responses can be incredibly frustrating to hear as a student. ... I aim to make sure that I don't [do this]”.

However, a deeper analysis of the responses shows that many tutor's interpretation of the theory and how it should be used was often constrained by misinterpretations, misunderstanding or their beliefs. For instance, despite the workshop focusing on moving students from being passive to active learners one tutor commented that to them self-determination theory;

“...illustrated the need for classrooms to integrate both passive and active teaching styles that direct students towards self-learning”.

We cannot be certain what this tutor meant, for example, passive teaching could mean letting students work things out for themselves. However, language used to scaffold learning activities that can be misinterpreted is likely to be problematic for students.

Many of the comments focussed on the concept of competence (some using “confidence” as an incorrect synonym)

“Competence ~ confidence, it is hard to become competent if you lack confidence that you can do something.”

“Yes, it made me realise that confidence is important. And how providing needed support is more fundamental than I thought at first. “

“Self determination theory is extremely useful ..... Believing in yourself and being confident is one of the first steps to succeeding at anything”

The frequent use of “confidence” may be obfuscating a lack of understanding of the meaning of competence in self-determination theory and again be problematic when used to scaffold activities and assist students. For example, students can be confident in undertake a task even if they are not competent. Future research is required to examine the level of understanding developed in the tutor training. In any case, these misconceptions suggest as a first step the need for mid semester follow-up workshops (after they have some tutoring experience) that include dialogue to socially construct the meaning of these terms and our intentions.
Complexity framework

Tutors were asked if they found the complexity framework and associated language useful and how they might use it in their class to improve student learning.

In analysing the tutor responses to the survey, it was found that while some reservations were expressed, overall tutors were supportive of the framework and the language. Tutors reported increased understanding and appreciation of what is required to manage complexity and an increased capacity to articulate this to their students.

They comment on the nature of student learning and how they feel they can use the framework and language to support their students:

“somewhat useful for giving me the vocabulary to explain these ideas [of complex problems] to students”

“These frameworks were particularly useful, as they illustrated the movement of students from knowledge consumers to knowledge generators. It illustrated the need to avoid the typical student mentality towards rote learning content, within a teaching environment. This was particularly useful, as a measure to encourage meaningful and useful learning processes for students”

Tutors believe the framework will assist them in scaffolding their learning activities for students, including being better able to explain the learning opportunities provided within open-ended, ill-defined projects. Comments specifically identified the link between the framework and the students understanding of the expected outcome of the learning activity:

“Its indeed helpful to explain to students why their learning activities are designed in a certain way and what they are meant to gain from them”

“Yes. I had thought in the past that the mindset of: “I don't know, but i can find out!” is important for people to have, but this supports that idea and defines it more explicitly, making it easier to adapt to learning tasks.”

There were comments that indicated some reservations on the part of tutors. Many of these were based on tutors’ beliefs and the traditional curriculum design used to teach many engineering topics that allows students to simply transitional from the knowable to the known:

“Personally, I think it depends on the course structure and content”

“To some extent. I believe this can be useful, however I think there is an extent to which this works and it comes down to using one’s discretion to best determine what will work.”

“Depending on the topics..”

“…I think uni needs to be better at setting problems that incorporate these "complex" less easy to answer problems. Its all well and good to explain to students that questions aren't as easy in the real world but we need more examples of it in the teaching outcomes and questions that are set.”

Interestingly, some tutors expressed a belief in the usefulness of the framework but their belief in repetition and moving from the knowable to the known (the transition depicted on the right-hand side of Figure 1) meant it was unlikely to inspire impetus for change.

“I think this is a useful framework to a degree. It is true that complex engineering problems cannot merely be solved through repeating past problems but I do think that the repetition will solidify some concepts into the minds of the students meaning that when they are presented with a complex question, their goal is to reduce it to a simplified problem that they can solve through known knowledge.”
Findings

While overall the response to the training, which included discussions introducing and using self determination theory and the complexity framework and language was positive, the tutors responses included:

- incorrect use of language discussing learning theory;
- reservations expressed in terms of the wide application of the complexity framework and language;
- personal resistance (often because of strongly held beliefs as to how knowledge and skills are exchanged in an educational context) to adopting the framework in classes where it may be applicable.

It is probable that in some cases this resistance is also due to the tutor’s own perception of competence, with several expressing the opinion that it was their job to provide students with answers and meet their needs. These factors suggest that there is a need to improve the training for tutors. A single session of tutor training describing the concepts is unlikely to be sufficient to overcome the tutor’s own misconceptions, misunderstandings and/or resistance, especially since some participants had limited and/or no previous tutoring experience.

Interestingly, many tutors stated the main reason they believe they were selected as a tutor was their previous achievement of a high grade in the subject.

We suggest that the tutor training would be more effective if it included a process described by Rust (Rust et al, 2003) in reference to learning academic standards, of socialisation involving observation, imitation, dialogue and practice with highly skilled tutors. This would allow a cycle of application (practice), assessment, feedback, dialogue and reflection to ensure both the concepts and associated language are well understood and can be clearly articulated. However, even if the required funding was available for such activities our recent experience of initiating a paid professional development teaching and learning program suggests it may be difficult to attract committed participants, with many potential candidates declining the opportunity as they did not see the value and/or benefit to their future professional engineering career.

Future research will look at whether tutors chose to apply the language and framework in their teaching, and whether the use allowed the co-construction of knowledge with their students, providing both tutors and students a language to understand, discuss and evaluate the associated learning outcomes.

Conclusions

The motivational need to feel competence is often inhibited when learners do not have a language and understanding of the expectations and processes involved. This is particularly visible when engineering students are asked to engage in learning activities that involve managing complexity as the required processes are often quite different from their previous learning experience and approaches. We investigated tutor’s perceptions of the usefulness of tools to understand, scaffold and facilitate student learning that involves managing complexity. We found that introducing tutors to self-determination theory and a complexity framework and supporting language generally increased tutor’s feelings of competence. Despite some reservations, they expect the use of the framework and language will allow them to more competently scaffold their learning activities to students, being better able to explain the learning opportunities provided within open-ended, authentic engineering projects.

We also find, not surprisingly, that tutor training workshops are a beginning and not an end to helping tutors develop the skills required to successfully facilitate their student’s learning. We suggest outcomes would be vastly improved if tutors were involved in temporally spaced observation, imitation, dialogue and practice with highly skilled counterparts. This would...
allow a cycle of application, assessment, feedback, dialogue and reflection to ensure both the concepts and associated language are well understood and can be clearly articulated.

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Engineering Education Re-interpreted Using the Indigenous Sacred Hoop Framework

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Abstract: This research-into-practice paper utilizes a reflective case study approach within a participatory action research (PAR) framework to describe the beginning journeys of three engineering educators from a large research university in Western Canada to learn about, and integrate Indigenous values, knowledges, perspectives, and design principles in engineering curricula. The educators attended a three-day workshop on incorporating diverse cultural perspectives and awareness into the foundation, facilitation, and curriculum design of teaching. The workshop utilized Indigenous perspectives and knowledges to create a more inclusive learning environment. By exploring their own Positionality, the engineering educators re-interpreted the Canadian Engineering Accreditation Board (CEAB) graduate attributes, one engineering course curriculum, and design for sustainability using an Indigenous Sacred Hoop framework. The educators learned that the Spirit aspect has significant impact on the three pillars of design for sustainability, and needs enhancement in engineering curricula, as the balance of the four aspects – Mental, Emotion, Physical and Spirit – will support the whole engineer. The finding is interpreted through the ontology of relationality. This work honours a shared history between Indigenous Peoples and non-Indigenous people, and commits to holding shared values and developing shared approaches in our work towards Truth and Reconciliation in Manitoba and in Canada.

Introduction and context
A colonized and racist history has marred relationships between Indigenous Peoples and non-Indigenous people in Canada. In a national effort to expose the truth of the dehumanizing treatment of Indigenous Peoples at the hands of non-Indigenous settlers, Canada struck the Truth and Reconciliation Commission (TRC) in 2008. Several of the ‘94 Calls to Action’ (2015) to redress the legacy of residential schools and advance the process of healing include reconciliation through education, which for engineering translates in part as the inclusion of Indigenous knowledges and perspectives into engineering education. There are several publications on Indigenous research methodologies (Battiste, 2013; Smith 2012; Kovarich 2009; and Wilson 2008), recent publications on incorporating aboriginal perspectives in engineering education in Australia (Goldfinch and Kennedy 2013; Kennedy et al. 2016), and resources such as the Canadian Journal of Native Education. However, the explicit and intentional incorporation of Indigenous values, knowledges, perspectives, and design principles in engineering education programs and research in Canada is still nascent.
As part of the University of Manitoba’s commitment to Truth and Reconciliation, the Strategic Plan (2015-2020) outlines a number of goals for the institution that focus on Indigenous engagement and advancement (University of Manitoba 2019). These include, “Foster[ing] the inclusion of Indigenous perspectives in research, scholarly work and other creative activities; Foster[ing] a greater understanding of Indigenous knowledge, culture and traditions among students, faculty and staff; and Weav[ing] Indigenous knowledge, cultures and traditions into the fabric of our University. As a result, there is a commitment across the university to begin the journey to learn about Indigenous perspectives and see our colonized, Western knowledges through an Indigenous framework.

In the Faculty of Engineering at the University of Manitoba, Indigenous knowledges and perspectives are framed around questions of how they are important to, and can enrich engineering design, how engineering design can be relevant to Indigenous Peoples, and how our faculty and students can learn and understand Indigenous values, knowledges, perspectives, and design principles. Engineering students graduating from accredited Canadian engineering programs must demonstrate specific competencies required by the Canadian Engineering Accreditation Board (CEAB). There are 12 competencies that are integrated into our courses: 1. A knowledge base for engineering; 2. Problem analysis; 3. Investigation; 4. Design; 5. Use of engineering tools; 6. Individual and teamwork; 7. Communication skills; 8. Professionalism; 9. Impact of engineering on society and the environment; 10. Ethics and equity; 11. Economics and project management; and 12. Lifelong learning. One approach to incorporating Indigenous ways of knowing, thinking and being in engineering education is to re-interpret these competencies and thus, engineering curricula, using an Indigenous framework. For example, the mandate of the NSERC Chair in Design Engineering in our Faculty is to promote the advancement of design knowledge in engineering education as design for sustainable development. Within the conceptual framework of sustainable development are the inherent principles of accessibility and inclusion (Sachs 2015; Report of the World Commission 2018), which are directed by our Faculty to emphasize Indigenous knowledges and perspectives (Beddoes and Friesen 2018). Design for sustainable development is imperative, and Indigenous approaches are naturally suited to broadening one’s thinking relative to design solutions, which is particularly critical in Manitoba, where 17% of our population is Indigenous (Statistics Canada, 2016).

This research-into-practice paper utilizes a reflective case study approach within a participatory action research (PAR) framework to describe the journey of three engineering educators in the Faculty of Engineering at the University of Manitoba to learn about Indigenous values, knowledges, perspectives, and design principles, and how to incorporate them in engineering curricula. Three engineering educators – authors of this paper – elected to enrol in a workshop entitled, wiingashk: Sweetgrass, offered by the learning and teaching centre at our institution. There, we met Leah Fontaine, one of the authors of this paper, an Anishinaabe/Metis/Dakota Indigenous Initiatives educator, who guided us – two non-Indigenous Canadian and one non-national, engineering educators – on our journeys’ beginnings. This paper describes the workshop, our processes to engage in learning about Indigenous worldviews by establishing our Positionality, and our understandings of how to re-interpret the CEAB engineering graduate attributes, one engineering course curriculum, and design for sustainability using the Indigenous teachings of the Sacred Hoop as the conceptual framework. It offers that the Spirit aspect has significant impact on the three pillars of design for sustainability, and needs enhancement in engineering curricula, as the balance of the four aspects of the Sacred Hoop – Mental, Emotion, Physical and Spirit – will support the whole engineer, a finding which is interpreted through the ontology of relationality.

The neglect to infuse diverse individuals and approaches that will result in new ideas and technologies in engineering and the prohibition of a diverse body of Indigenous Peoples to see themselves in engineering (Cape Breton University, 2006), results in an inability to engage the challenges of the future (Smith and Schank Smith, 2003). By re-interpreting
engineering education with an Indigenous framework, it is speculated that Indigenous students will see themselves in engineering curricula and thereby find belonging in and enrich the profession (Cape Breton University, 2006). This paper offers a cultural framework by which to improve engineering curricula through the balance of Western and Indigenous perspectives. This approach supports engineering faculty and students to gain a deeper understanding of, and appreciation for Indigenous cultures, values, perspectives, and knowledges, which will ultimately benefit all Indigenous Peoples and non-Indigenous people in engineering practice.

Research questions

This research-into-practice paper was guided by the questions, How are Indigenous perspectives inherent in the CEAB graduate attributes (i.e., engineering competencies)?, How do engineering competencies manifest in engineering curricula using an Indigenous framework?, and How are Indigenous perspectives inherent in engineering design for sustainable development?.

Conceptual framework

Sacred hoop

The first of a series of workshops entitled, wiingashk: Sweetgrass, (University of Manitoba, 2018) that uses a Sacred Hoop framework was introduced by Leah Fontaine, (Anishinaabe/Metis/Dakota), who is an Indigenous Initiatives Educator in the Centre for the Advancement of Teaching and Learning at the University of Manitoba. Fontaine (2018) expressed that the Sacred Hoop is a framework that makes relationship connections, whether they are Indigenous or not, through four segments: The North is the Mental aspect, the South is Emotion, the West is Physical, and the East is Spirit, which can be interpreted as What have I learned? How did I get here? Where am I going? and What is my story?. The centre of the Sacred Hoop is the intent – or one’s position, determined by relational aspects to land, people, and colonialism. Fontaine demonstrated how she used the Sacred Hoop framework in her own research as an artist to create a lens through which to view Aboriginal art for the purpose of healing (2010). Fontaine (2010) described the significance of the Sacred Hoop: “Its circular form encompasses categories to help us expand our way of organizing information and allows for insights and connections that may be overlooked in less circular ways of thinking. It celebrates and unifies our four human aspects without isolating or compartmentalizing our diverse understandings” (p. 41).

Methodology

This research-into-practice paper utilized a reflective case study approach within a participatory action research (PAR) framework to describe the journey of three engineering educators in the Faculty of Engineering at the University of Manitoba to learn about Indigenous values, knowledges, and perspectives, and how to incorporate them in engineering curricula. A participatory action research (PAR) approach is a qualitative research methodology anchored in action research, which is the “systematic collection and analysis of data for the purpose of taking action and making change” by generating practical knowledge” (Gillis & Jackson, 2002, p. 264 as quoted in MacDonald 2012, p. 35), for “the overarching goals to ‘equalize power differences, build trust, and create a sense of ownership in an effort to bring about social justice and change’” (Castleden et al., 2008, p. 1394 as quoted in Sjoblom 2018). PAR was a suitable methodological approach for this research-into-practice work on a number of levels: It supports the participation of a community – in this case the engineering educators, the Indigenous Initiatives Educator, and the interaction of Western and Indigenous worldviews. It is circular in nature, “encompass[ing] a ‘cyclical process of fact finding, action, reflection, leading to further inquiry and action for change’” (Minkler, 2000, p. 191 as quoted in MacDonald 2012, p. 37), which
reflects the Sacred Hoop conceptual framework and Indigenous circular approaches to knowing and being. Moreover, PAR philosophically aligns with our commitment to design for sustainable development, as “PAR’s philosophy embodies “the concept that people have a right to determine their own development and recognises the need for local people to participate meaningfully in the process of analysing their own solutions, over which they have (or share, as some would argue) power and control, in order to lead to sustainable development” (Attwood, 1997, p. 2, as quoted in MacDonald, 2012, p. 36). Using PAR enabled the engineering educators who attended a workshop as part of their journeys to learn about Indigenous worldviews, to critically reflect on their leanings, and come to know how to include Indigenous values, knowledges, and perspectives in engineering education. The workshop description, an explanation of Positionality, and the educators’ own Positionalities are shared here.

**Positionality**

During the workshop, the engineering educators learned that relationships are critically important to Indigenous communities; they may be considered foundational to Indigenous ways of knowing and being (Battiste, 2002). To be good teachers, we must build relationships with our students. To build relationships, we must first know ourselves. The Indigenous Initiatives Educator, Leah Fontaine, who shares authorship of this paper, referred to this as “Positionality.” Fontaine quoted Battiste (2013) to explain Positionality as the importance of knowing one’s ontology and philosophy in relation to community-based knowledge:

> Wilson aims to put the contingent relational element to this research work, noting that while Indigenist research does not require that one be Indigenous, it does require one to support and articulate one’s ontology and one’s philosophy and research in relation to context-based knowledge that is community-based, not book or literature-based knowledge. In other words, the context is derived not from theory from academics but from peoples and collectives and related to place. Then one is connected to community and to place, the relational aspects of communities, people, families, and their context become the important elements of how to proceed with knowledge search and production. It grounds one’s protocols and thus research processes as Graveline used in her “In-Relation pedagogy” (Graveline, 1998). (Battiste, 74)

To begin this research journey, three authors position ourselves in the centre of the Sacred Hoop, at the beginning of our journeys, as guided by Fontaine. This practice grounds us, and gives the reader the perspectives from which we approach this research-into-practice paper. By locating ourselves in our own history, we think about and understand how we are connected to our community and to place, which grounds us as we search for knowledge and build connections and relationships. We position ourselves as two White women of European descent, and one African woman, who live in Treaty One Territory, on the traditional lands of the Anishinaabeg and the homeland of the Métis Nation, in Winnipeg, at the crossroads of the Anishinaabeg, Métis, Nehiyawak (Ne-hi-ya-wak), Dakota and Oji-Cree Nations. We are sharing our beginning understandings of Indigenous culture as has been taught to us, and with permission, by Leah Fontaine.

**Jillian’s Positionality**

My Mum’s people are settlers in Australia who originated from Ireland. My Dad is a first generation settler to Canada whose parents emigrated from the Ukraine at the onset of the Second World War. Despite my diverse cultural roots, my identity lies in the land – the evergreens, granite rocks, lakes and river waters of the Canadian Shield, the trembling aspen and birch of the Boreal forest, and the wide open skies of the Manitoba prairies. I am a first and second-generation settler to Canada, who grew up with a limited understanding of the plight of the Indigenous Peoples. I know that I’ve had the privilege to commune with this land we call Canada, and grown up with freedom and privilege, while Indigenous Peoples have not. I recognize that I must work to understand the harms that settlers to Canada have
done to Indigenous Peoples. This knowledge will inform the way that I live my life, and the ways in which I teach and learn with my children and students. We must find a way forward together. Our children’s future depends on it.

Carolyn’s Positionality

I am a second generation Canadian. My mother’s parents were wealthy business people from the Russian Ukraine, who came to Canada to avoid losing their fortune, their religious freedom and possibly their lives when the Communists took over. My mother was a nurse. She took positions of leadership that are usually reserved for doctors. She led organizations whose members were all male. My father’s family lived simply in the Russian Ukraine until the threat of religious persecution became a reality. The family immigrated to Canada to find safety. The family continued to live a simple farm life in Canada. My father was a Professional Engineer for a short time and became a long time high school math and physics teacher. He took time away from his career to volunteer for two years, working for a Northern Indigenous community to market and sell their products – Wild Rice and Blueberry Jam – in the southern cities. I live in the space between my two families. Like my mother, I am independent and work in a male dominated organization. Like my father, I am a Professional Engineer and a teacher who likes to volunteer and offer people support. I want to gain knowledge and teachings to be able to start to see the Indigenous students’ knowledge and help them see it within the academic setting of my classroom. The journey is starting with the shift of my view of the course curriculum. I try to see it using an Indigenous framework. If I start shifting, maybe my students will help shift the view as well.

Afua’s Positionality

My first name is my “soul name” as a Friday-born girl from the Akan Clan in Ghana. My middle name is from my Great Grandmother from my father’s lineage from the Akuapem Traditional Area. I have had the opportunity to have two last names, my maiden (Ampadu-Mintah) and current (Mante), connecting me to the Kwahu Traditional Area and the Akuapem Traditional Area, respectively. My name is a reminder that I belong to a wider community. My connectedness to kin instills in me a sense of pride, a pride that has informed the choice of names for my children. I am always proud to tell my children and explain to others what their names are connected with and what that means. I grew up in Ghana. Ghana has had her experience with colonialism. Through the “blood and toil” of my forefathers, the country became free. I lived free in my homeland; A freedom that allows me to dream and realize my dreams; A freedom that allows me to explore other parts of the world for opportunities to advance myself. And the freedom to call Ghana my home! As a relatively new immigrant to Canada, I have had the opportunity to learn from Leah about the Indigenous peoples of Canada. My acquired knowledge has deepened my perspective about connectedness to land and kin. This deepened perspective guides me in my current role to find meaningful ways to enhance students’ social awareness and advance students’ training towards sustainable developments at the Faculty of Engineering at the University of Manitoba.

Findings and Discussion

The findings of this work include three reflective case studies primarily grounded in the authors’ re-interpretation of our engineering understandings and engineering education research through the Indigenous framework of the Sacred Hoop. We discuss the interpretations of the CEAB graduate attributes (i.e., engineering competencies), one engineering course curriculum, and design as sustainable development.

CEAB graduate attributes as seen through the Sacred Hoop framework

One author, prior to this journey, had conducted an exploratory case study to investigate how key engineering stakeholders perceived the dependency of one CEAB graduate attribute on another to reflect their interconnectivity in engineering practice (Seniuk Cicek et al. 2017; Seniuk Cicek et al. 2019). The findings were interpreted to support a new framework of
clusters of graduate attributes (Seniuk Cicek et al. 2018). The framework was proposed as a tool for engineering curriculum development, where rather than treating the graduate attributes individually, they could be interpreted in the four clusters to support their interconnectivity in engineering practice. The four clusters were conceptualized as, *Problem Solving Skills, Interpersonal Skills, Ethical Reasoning, and Creativity and Innovation*, and were further interpreted to correspond to Bloom et al.’s (1956) three Domains of Cognitive, Psychomotor, and Affective Learning. With the help of our Indigenous Initiatives Educator guide, Leah Fontaine, the findings from this study were looked at again through the Indigenous framework of the Sacred Hoop, where the four aspects became the foundation for this conceptual framework. The Problem Solving Skills cluster (knowledge; cognitive) are positioned in the North/Mental aspect (What have I learned?); Ethical Reasoning (feelings; affective) in the South/Emotion aspect (How did I get here?); Interpersonal Skills (feelings; affective) in the West/Physical aspect (Where am I going?); and Creativity and Innovation (hands-on, skill-based; psychomotor) in the East/Spirit aspect (What is my story?) (Fig. 1).

**Fig. 1: Seeing engineering competencies and design for sustainability through the Sacred Hoop framework.** (Image: Madeleine Dafoe and Chris Laing, University of Manitoba.) (Icons: Leaf by Adrien Coquet; Fire by Travis Avery; Wind by B. Agustín Amenábar Larraín; Water by Abdul Karim from the Noun Project.)

The Sacred Hoop not only supports the knowledge, skills, attitudes, values and behaviours that comprise the CEAB graduate attributes, and the cognitive, psychomotor, and affective domains of learning (Bloom et al. 1956), but remind us that we do not traditionally nor easily support the Spirit aspect in engineering education. The call to support students' development of creativity and innovation as as critical engineering competency (Radcliffe, 2005; Robinson et al. 2005, p. 128; Male 2010, p. 35), also underscores the need to develop the Spirit aspect in teaching and learning in engineering education.

**An engineering course as seen through the Sacred Hoop framework**

The interpretations of how the CEAB graduate attributes cluster in the Sacred Hoop demonstrated that the next step could be to position an individual course within this framework. The first-year Introduction to Engineering Design (ENG 1430) course is intended to introduce engineering students to a wide range of topics with a focus on a range of the CEAB graduate attributes. These include the design process, ethical considerations, professional behaviour, safety, working in teams and communication. A total of 10 of the 12 CEAB graduate attributes are described in the ENG 1430 course outline. The course is
structured to lay a foundational understanding of these competencies so that students will develop expertise in these areas as they move through their engineering programs. ENG 1430 is students’ first step on their path to acquiring the attributes of an engineer.

Within the Sacred Hoop, we situated Problem Solving in the North/Mental. For ENG 1430, this would include the knowledge of the design process and the problem-solving techniques that are included in lectures and the textbook. The South/Emotion comprises the Ethical Reasoning attributes. In ENG 1430 students are expected to demonstrate professionalism as it relates to professional engineering. Students are introduced to safety and the professional engineer's obligation to public safety. The West/Physical aspect of the Hoop contains the Interpersonal Skills. In ENG 1430 students apply principles of teamwork in a design setting. They also work in teams to apply the principles of project management to open-ended design problems. These projects are documented and presented through individual journals, meeting minutes and project reports. The East/Spirit aspect of the Sacred Hoop describes Creativity and Innovation. The students in ENG 1430 are given the opportunity to create solutions to problems using the engineering design approach to solve open-ended problems. Students are encouraged to express themselves and tell the story of their work through graphics and sketches to accompany their designs.

Through the process of situating ENG 1430 in the Sacred Hoop, a way has been found to express what was intrinsically and unconsciously known by the authors: that there must be a balance of the four aspects – Mental, Emotion, Physical, and Spirit – to be a good engineer. This is not always understood or expressed. For example, the professional skills aren’t always considered to include the ethical measure of an engineer’s responsibility. Ethics are perceived important when working with a client, but ethics may not be inherently included in the solution or design. In actuality, one must be ethical throughout every aspect of being an engineer. Similarly, many don’t think about Spirit when they ask, Am I a good engineer? They think about, Am I good at math? Creativity is inherent in the Spirit – and it’s connected to all the other attributes. It’s about the importance of all of the attributes in each of those quadrants converging. The Sacred Hoop articulates this in a key way: You have to have Spirit to be a good engineer, just as you have to have the Mental, Emotion, and Physical aspects as well. Using the Sacred Hoop as a framework for the graduate attributes provides a way of describing that there are individual attributes required to be an engineer but they all move together to represent the whole engineer. This foundational engineering course balances the Sacred Hoop quadrants. The Sacred Hoop reaffirms the wide breadth of the course, and our diverse approach to engineering. It lays the foundation for students understanding engineering, and becoming engineers.

Design for sustainability as seen through the Sacred Hoop framework

The engineering training requires students to have the ability to understand the role of engineering in both technical and societal contexts without separating the two when making engineering decisions (Dukhana et al, 2012; Engineers Canada, 2017). One way to ensure this is to integrate sustainability concepts into the engineering education (Engineers Canada, 2017). Sustainability addresses challenges by considering the three main pillars of sustainable development: economic, social, and environmental development for the total wellbeing of human life (Sachs, 2015). Through the Design Chair initiative, our faculty has adopted design for sustainable development as the conceptual framework for our engineering programs. In the workshop, under the guidance of our facilitator, Leah Fontaine, the concepts of design for sustainable development were integrated in the Sacred Hoop framework. Economic development is situated in the North/Mental aspect; social development is situated in the South/Emotional aspect; environmental development is in the West/Physical aspect; and culture of a society or a person is positioned in the East/ Spirit aspect (see Fig. 1). We discovered, through this process and Indigenous perspective, that a society/person’s culture, which is positioned in the East/ Spirit aspect, has significant impact
on how well the three pillars are addressed when making engineering decisions. This is because problem identification or solutions to a problem are based on one’s perspectives. Perspectives are developed based on culture, where culture is defined as the norms, values, beliefs, expectations, and conventional actions of a group (Aikenhead 1996). Considering the continuous interaction and interconnectedness of all aspects of life, our understanding of the importance of the Cultural/ Spirit aspect of societies will be significant to finding holistic solutions to our current world crises to create a balance in our lives and environment.

The Ontology of Relationality

Overall, from the three reflective case studies primarily grounded in the authors’ re-interpretation of the CEAB graduate attributes (i.e., engineering competencies), one engineering course curriculum, and design as sustainable development, the educators have come to recognize that the Spirit aspect in the Sacred Hoop has significant impact on the three pillars of design for sustainability, and needs enhancement in engineering curricula, as the balance of the four aspects – Mental, Emotion, Physical and Spirit – will support the whole engineer. This finding may be interpreted through Elizabeth A. Lange’s (2018) work as the “ontology of relationality.” According to Lange (2018), the ontology of relationality describes “The intuitions of balance, harmony, and wholeness that occur for a learner” (p. 281). The “wholeness” that we are describing is actually grounded in the ancient holistic worldviews of Indigenous Peoples and Eastern philosophies (Lange, 2018, p. 287). As described in Lange (2018) by Paula Gunn Allen (1986/1992), who is a Laguna Pueblo Indian from New Mexico,

...sacred hoop conveys that reality is a singular unity that is dynamic and encompassing . . . [P]eople acknowledge the essential harmony of all things and see all things as being of equal value in the scheme of things, denying the opposition, dualism, and isolation (separateness) that characterize non-Indian thought. The tribal person perceives things not as inert but as viable and alive, and he or she knows that living things are subject to the processes of growth and change as a necessary component of their aliveness. (p. 288-289)

The Western worldview is dominated by “logical empiricism” in contrast to Indigenous worldviews that are guided by “relationship, process, and change” (Lange, 2018, p. 289). Lange (2018) believes that true transformative learning and change, which she argues is required for environmental sustainability, must be rooted in the ontology of relationality. In this model, “transformative learning and sustainability education would attend to the dynamics of the whole, and nested systems as much as possible... and [provide] opportunities for students to name the systems they are nested within, their positionality, the porous boundaries between systems, and to experience these connectivities” (p. 291). This would ultimately support “ethical, ontological, and epistemological transformations in the journey toward creating socially just and regenerative cultures” (Lange, 2018, p. 184).

The authors of this research-into-practice paper were led to the ontology of relationality through a reviewer’s response to their re-interpretation of engineering competencies, curricula, and design for sustainability through the Sacred Hoop framework, and the recognition that the Spirit aspect needs attention in engineering education in order to develop “the whole engineer.” Through the balance of Western and Indigenous perspectives, “conditions for transformation” (Lange, 2018, p. 295) have been revealed.

Conclusions and Next Steps

This research-into-practice paper utilized a reflective case study approach within a participatory action research (PAR) framework to describe the beginning journeys of three engineering educators from a large research university in Western Canada to learn about, and integrate Indigenous values, knowledges, perspectives, and design principles in engineering curricula. The educators attended a workshop on incorporating diverse cultural
perspectives and utilizing Indigenous perspectives in the foundation, facilitation, and curriculum design of teaching to create a more inclusive learning environment. By exploring their own Positionality and understandings of how to frame the CEAB engineering graduate attributes, one engineering course curriculum, and design for sustainable development using the Indigenous Sacred Hoop framework, the educators learned that the Spirit aspect has significant impact on the three pillars of design for sustainability, and needs enhancement in engineering curricula, as the balance of the four aspects – Mental, Emotion, Physical and Spirit – will support the whole engineer. This “wholeness” is interpreted through the ontology of relatedness.

This work honours a shared history between Indigenous and non-Indigenous peoples, and commits to holding shared values and developing shared approaches in our work towards Truth and Reconciliation in Manitoba and in Canada. However, it is only the beginning, with a tremendous amount of learning and work still needed. In particular, the authors have been encouraged to share these interpretations with others, and particularly with students who have Indigenous values, knowledges, and perspectives, as the authors explore how to teach these concepts and change engineering curricular material, content, and assessments to enrich engineering education.

It is our intention that through the commitment of improving engineering education by enhancing curricula with Indigenous values, knowledges, perspectives, and design principles, Indigenous students will see themselves in engineering, and be encouraged to bring their diverse perspectives and knowledges to the profession. Ultimately, through the diversification and enrichment of engineering with Indigenous ways of knowing, understanding, and being, all undergraduate students will be better equipped to practice good engineering in Manitoba, across Canada, and globally, throughout the world.

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Shifting design literacy practices in mechanical engineering: Multimodal social semiotic analysis of first and final year design reports

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Abstract: Design is an important part of any mechanical engineering programme, as can be seen in the number of such programmes that culminate in a capstone design project and achievement of an exit-level design outcome. This paper interrogates the extent to which a particular mechanical engineering programme develops students’ mastery of design practice. This is undertaken through a framework that positions literacy as a multimodal social semiotic practice. First and fourth year design reports were collected from students who gave consent for their reports to be used, and over 500 pages of data was analysed. The analysis compares the first and final year students’ design practices as made evident in the reports they submitted. The findings suggest that fourth year students have overcome most challenges encountered by the first years, but that curricular efforts have not ensured that all final years display mastery of the conventional demands associated with design literacy. The implications of this are discussed.

Introduction: Context and research question

Previous research conducted by the authors (Simpson and Bhamjee, 2017) reveals that first year mechanical engineering students experience challenges with regard to developing an engineering design ‘voice’ in their design reports. These challenges emanate from a lack of confidence in their own design abilities that is exacerbated by a lack of access (physical and epistemic) to the technological resources of design. However, design is an important outcome of any mechanical engineering study programme, as can be seen in the fact that many mechanical engineering programmes include a capstone design project that is meant to demonstrate achievement of an exit-level design outcome. Achievement of such design outcomes requires focused effort aimed at developing students’ design practice within a programme.

This paper extends the work of the previous paper by comparing first and fourth year design reports and examining the extent to which a particular mechanical engineering degree programme is developing students’ mastery of design practice at the level expected of a candidate engineer. This research was conducted at a large public university in Johannesburg, South Africa. Within this context, there is a large discrepancy in students’ access (physical and epistemic) to the resources (technological and semiotic) of design activity. It is thus imperative to examine the extent to which programmes of study support the achievement of design outcomes amongst the entire student cohort, rather than an elite, highly-resourced few.
Theoretical framework: Literacy as multimodal social semiotic practice

The notion of literacy as multimodal social semiotic practice implies a number of complex arguments about literacy, a term that is often taken for granted as simply referring to the ability to read and write. However, reading and writing are social acts - moreover, they are sociopolitical acts. Access to literacy is a sociopolitical issue in that literacy opens up avenues for participation in social and political life as a citizen of a country (Janks, 2010), and where literacy is curtailed, so too is such participation. Literacy is thus a social act (Barton, Hamilton and Ivanič, 2000). A most obvious example of this, in the context of the present paper, is the fact that students, upon entering the higher education system, are expected to have obtained a certain level of literacy that will enable them to participate in the core activities of higher education (Lea, 2008; for a seminal text on this point, consult Bartholomae, 1985).

An important consideration in the study of literacy is that, because the activities of various social institutions are different, so too are the types of literacy that are required. The school, the family, the church, the university, government spaces, and corporate spaces all engage in different activities and, as a result, use language differently and for different purposes (this argument was pioneered in the 1980s, notably in Shirley Brice Heath’s Ways with Words, published in 1983). The priest does not need to engage with a research essay, just as the professor does not need to engage with a hymn book. Literacy is thus a practice: the practice of literacy in one social field (such as engineering) is different from the practice of literacy in another (such as law, for example).

One of the ways in which different social institutions and fields practice literacy differently is in the resources that are used. In science and engineering, for example, written or spoken language (words) seldom occur alone. The written text is, usually, accompanied by diagrams, tabulations, Cartesian graphs, photos or technical drawings. Similarly, spoken language is augmented by PowerPoint presentations, physical models or artefacts, manufactured objects, or drawn designs. Engineers thus use multiple ‘representations’ (Johri et al., 2013) to accomplish their work. These images, graphics and so on have “epistemic importance” (Gross and Harmon, 2014: 2), that is, they assist in creating meaning within the texts in which they appear. As such, literacy is also multimodal in that, to fully understand a literacy practice, researchers and practitioners often need to look beyond the words alone as language, particularly in a social domain such as engineering, carries a limited share of the overall meaning of a text.

Finally, all of the above suggests a view of literacy as semiotic. Literacy involves using resources (linguistic or otherwise) in particular ways within specific contexts (van Leeuwen, 2005). The resources people use, therefore, are indicative of their social roles, their positions and the institutions to which they belong (Kress, 2010). That is to say, part of what distinguishes qualified engineers, for example, from others is the ways in which they are able to use the resources (signs and symbols, drawn, scientific, mathematical etc.) of the engineering profession, and their use of those resources further signifies the underlying knowledge and skill they possess.

The view, then, that literacy is a multimodal, social, semiotic practice is integral to the particular concern of the present paper. This concern is with the extent to which students - at both first and final year - have acquired the particular literacy practices associated with mechanical engineering design. This is important, in the first instance, as it offers insight into the students’ underlying assumptions and knowledge about engineering design which has implications for the practice thereof. In the second instance, it offers insight into the extent to which the mechanical engineering programme is working to the benefit of all students. As students enter the programme with different literacy resources, the programme of study must work towards overcoming this difference by enabling each and every student to achieve success and acquire mastery of the literacy of design.
Research context and methodology

First and fourth year design reports were collected for analysis in this study. The first year report required that students design a mechanical clutch for a one tonne truck. The design was to include the coupled shafts. In total, the report was not to exceed fifteen pages (excluding front matter and appendices). The assignment brief stipulated that a complete set of manufacturing (working) drawings were to be included in the report. The project was directly related to the module content which covered friction clutch and shaft design. In the case of the final year design project, each student was assigned a unique project. The project topics were provided by the supervisor or developed in consultation between the supervisor and student. The topic had to meet certain criteria to ensure that the required exit level outcomes could be assessed. The major criterion was that the project had to be representative of a complex and ill-defined design problem, as is usually encountered in practice. The second criterion was that the project should not be an investigation, rather it should be the design of a mechanical component or system wherein an industry-standard set of manufacturing drawings was to be produced. In all instances, students were required to develop a design solution through analysis of specifications and functional requirements, development of multiple concept solutions and sketches, and manufacturing drawings. The second author on this paper acted as the module lecturer for the first year students and project supervisor for the final years.

In total, 30 first year design reports (each between 10 and 15 pages) and 4 final year design reports (each at least 60 pages in length) were collected. This total of over 500 pages of data was analysed using techniques from multimodal social semiotic analysis, which involved examining how various semiotic resources are used and to what effect they are used in the texts that the students produced. Through a series of rounds of analysis, the data was analysed in terms of how students incorporated concept sketches, specification tables and final working drawings into a design narrative. This involved undertaking counts of instances in which students attempted certain meaning-making actions (such as, linking an image to the text) and examining how they enacted these attempts. Such analysis allowed for consideration of students’ confidence with and control over the design process and the extent to which they were able to demonstrate such confidence and control through the development of a design ‘voice’.

All students gave informed written consent for their reports to be used for research and this study was approved by the relevant Faculty Ethics and Plagiarism Committee.

Findings and conclusions

Previous research conducted by the authors (Simpson and Bhamjee, 2017) focused on the literacy practices of first year mechanical engineering students as they engage in engineering design. The present paper builds on this previous research by comparing first and fourth year design reports in order to examine the extent to which a particular mechanical engineering degree programme is developing students’ mastery of design practice at the level expected of a candidate engineer. In the discussion that follows, we focus our analysis on image production, language use, integration of language and image as well as the use of technology. At the same time, we frequently reference the findings of the previous research so as to reserve space in this paper to address the particular aims proposed herein, namely comparing first and fourth year design literacy practices.

Image production

Analysis and comparison of the first and fourth year reports revealed notable improvement in the quality of image production between the first and fourth years. The fourth year students were more comfortable with generating concept sketches that were their own production, while the first years often produced no concept sketches or concept sketches that were copied from other sources.
Of the first year reports, ten percent did not include any concept sketches, suggesting that the important role of conceptualisation within the design process was not yet sufficiently emphasised. As Ayer, Messner and Anumba (2014) argue, engineering design requires creative as well as analytical skills. While the majority of first year reports did contain concept sketches, a significant number of these included concept sketches that were copied from other sources, as seen in Figure 1.a. In these instances, it was understood that many first year students have not yet gained confidence in their agency as designers. However, in the case of the fourth year students, all of the analysed reports contained two or more concept sketches. In some cases, these concept sketches included more than one sketch or view for a given concept, as seen in Figure 1.b. Inclusion of multiple views is important as it is used to highlight key features of a specific concept otherwise not apparent in the initial concept sketch, as can also be seen in Figure 1.b. Moreover, inclusion of multiple views shows sustained engagement with each individual concept and thus suggests more thoughtful selection of a final design solution.

Moreover, the first year students’ concept sketches did not include anticipated or constrained dimensions, operating principles or highlighting of key features, as is also evident in Figure 1.a. In contrast, the fourth years were more adept at incorporating these features despite the fact that the concept sketches were hand drawn (see Figure 1.b). This is important because engineering design is a "socio-material process of observing and inscribing extracted recognitions ... and collecting and combining these recognitions into new recognitions by drawing them together" (Juhl and Lindegaard, 2013: 44). Provision of dimensions, operating principles and other key features demonstrates facility with regard to drawing the various facets of design together.
In terms of the working or manufacturing drawings, the difference between the first and fourth year texts suggests a shift from concept-level sketching to manufacturing drawing standard. This is evident in the higher standard of manufacturing drawings present in all but one of the fourth year reports, an example of which can be seen in Figure 2.b. Working drawings were present in less than ten percent of the selected first year reports. Of the first year reports that did contain working drawings, these drawings were often akin to concept sketches of a dimensionless assembly, as seen in Figure 2.a. Only one of the first year reports that did contain working drawings included dimensions. This suggests that, at first year level, the important link between design and manufacture, more specifically “how design fits into the broader engineering process” (Simpson and Bhamjee, 2017), is unclear for many students.

In contrast, most of the fourth year students exhibit mastery of design drawing practice at the level expected of a candidate engineer which implies that, at least in this aspect, the curriculum has supported them in acquiring the necessary skills within the programme of study.

**Language use**

In our previous study (Simpson and Bhamjee, 2017), it was shown that the first year cohort of students (which was a different cohort than the first year group under study in this paper), focused on fact-telling albeit that some evidence suggested the emergence of a design voice. The present analysis similarly found evidence of sentence structures that privilege voices from the literature at the expense of the students own voice. Thus, it is evident that both in their production of images and in the language they use, the first year students appear reluctant to insert themselves into their design practice, preferring reliance on the literature and on copied images over individual brainstorming and the creative act of conceptualisation of engineering designs.

However, there was also some evidence of first year students taking ownership of the design process. This was evident in sentences that informed the reader about how design choices were made, such as, “Before any friction clutch is chosen …” and “The designed clutch was …”. Such phrases signal the emergence of a design voice, but were limited in their use within the first year design reports.

In the case of the fourth year student reports, there was less reliance on and preoccupation with the literature. This is not to say that ‘fact-telling’ was not present in these reports, but that this was limited to the early sections of the report and that the discussion presented ultimately moved beyond mere fact-telling to privilege the voice of the student-designer. The
fourth year reports suggest that these students were better able to express a design voice by relating their designs to the knowledge presented in the literature. Thus, these students moved beyond the reporting of facts to the use of those facts to make selections and decisions in the process of design. This was evident in phrases such as, “...providing useful information which will assist the design process when brainstorming concept solutions...” and “This information, presented in this section, lays a solid foundation, for the design, and design considerations in the following section...”.

Integration of language and image

As per our previous study (Simpson and Bhamjee, 2017), the present analysis reveals that students use one or a combination of four strategies for integration of language and image, namely layout, lexis, captioning and reference. The primary mechanism employed by the first year students is layout, wherein the only linkage made between the two modes of representation is the proximity of the image or tabulation to the text. This can be seen in Figure 3. a. However, there are numerous instances of the other mechanisms being employed by some of the first year students. Nonetheless, it was seldom amongst the first year cohort that all four mechanisms were deployed. In contrast, Figure 3. b. is an extract from one of the final year students’ reports. It illustrates the usage of layout, lexis, captioning and reference. Apart from the proximity of the discussion on pipe coupling to prevent unhygienic conditions and the image of pipe coupling for health purposes (layout), common terms (“pipe coupling”, “health”, “hygiene”) appear in both the text and image, thus creating a link between the two. Thirdly, the caption that is provided below the image alerts the reader to the link between the discussion and the image. Finally, the student uses a textual reference to the figure in the middle of the paragraph to direct the attention of the reader to the salience of the figure.

Figure 3: Extracts from first and final year student reports: a) first year report using layout as only mechanism to link language and image, and b) fourth year report using layout, lexis, captioning and reference to link language and image.

In the case of the fourth year reports, it was common to see the use of all four mechanisms for integration of language and image, as seen in Figure 3. However, there were a number of cases in the fourth year reports in which images or tabulations were missing captions. Thus, a challenge that remained with the fourth years were lapses in the integration of language and image, though these appeared to be a result of lapses in concentration rather than misunderstanding of the convention. The integration of language and image through layout,
lexis, captioning and reference is important as it is a signifier of control over the design process when students are able to weave language and image together into a coherent whole rather than relying on the reader to make connections between the provided discussion and images.

**Use of technology**

Amongst the key challenges that the first year students faced was a lack of familiarity with the technologies for design literacy. However, the fourth year students showed a greater level of comfort and familiarity with the technologies of design. While the fourth year students produced computer-generated concept sketches, the first years inserted these images as photos taken with a phone or relied on images copied from the literature, as seen in Figure 4. Furthermore, the final years were better able to integrate their design drawings and calculations into the text of their design report as opposed to the common first year practice of relegating these to a hand-drawn appendix or separate document.

To illustrate the first and final years’ relative comfort with technology, compare, for example, the different ways in which design calculations are presented in the two excerpts presented in Figure 5. Figure 5.a. is an extract of a first year design report. As can be seen, the design calculations – which are heavily reliant on mathematical symbolism, rather than language – are written by hand, a photograph of which is then incorporated into the design report. In contrast, the fourth year student, whose work is shown in Figure 5.b. has generated the design calculations in MS Word.
Implications, limitations and recommendations

In our previous study (Simpson and Bhamjee, 2017), it was shown that first year students operate in a state of interim literacy (Paxton, 2007) in the sense that they are in a process of acquiring a design ‘voice’. Amongst the key challenges that first year students face are a lack of familiarity with the technologies for design literacy, uncertainty regarding the role of design in engineering activity leading to a disjoint between ‘design’ and ‘manufacture’, and preoccupation with the literature as opposed to critical analysis of the literature to inform their own work. These challenges continue to be seen in the sample of first year design reports analysed herein.
Despite notable improvement on the part of the fourth years, it was seen that one of the final year students continued to produce working drawings that did not display mastery of design. In this instance, the report did not contain manufacturing drawings that were to the required standard. This suggests that some final year students continue to require intervention and support regarding the important role that the working drawing plays in connecting the mechanical engineering processes of design and manufacture. Such intervention may assist these students to better grasp the link between design – as an engineering activity – and manufacturing as the ultimate goal of design. These interventions would not necessarily need to be aimed at changing the curriculum, but at placing particular emphasis on certain aspects of the design process. It is worth noting that the department in question has already given considerable thought to the development of a design stream of courses within the programme in order to develop graduates’ design abilities.

In addition, it should be noted that the fourth years benefitted from individualised supervision and had much greater time for drafting, feedback and redrafting, a luxury that the first years did not have. The academic who supervised the fourth year students (the second author of this paper) reflected that, in most instances, the initial concepts developed by these fourth years were largely derivative of one another. That is, the concepts developed in the early phases of the project were not unique or discrete concepts. Rather, one concept was unique while the others were similar to the first with minor modifications. This suggests that some final years also require support regarding the important role of conceptualisation in engineering design. The students need greater emphasis on the need for multiple unique concepts, which enhances the likelihood of finding the most appropriate solution to a design problem. However, with focused input provided as part of the supervision process, the fourth year students overcame this challenge by the end of the project.

Based on this, to more fairly compare the design literacy practices of first and fourth year students, one would need to consider the entirety of the fourth year design project, beginning with early drafts and early concept sketches. This would allow for isolation of what practices are developed during the course of the first three years of the programme, and which practices are developed instead through the capstone process of completing a design project. Finally, it should also be noted that this study has examined students’ texts and what these indicate about the students’ approaches to design, and has not examined students’ stated or implicit perceptions of or learnings about the design process.

References


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Teaching geotechnical engineering for practice-readiness: An action research project

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Abstract: Innovative pedagogical approaches are necessary to equip students with the engineering judgment and critical thinking necessary for the design of geotechnical engineering structures. This paper investigates the effectiveness of a suite of pedagogical strategies aimed at better preparing students for the challenges of engineering practice using an action research design. The interventions implemented included a mini-design project, a guest lecture, use of specific geotechnical software, and a term paper on a significant geotechnical problem encountered in practice. Data was collected in the form of a student survey that sought to understand students' perceptions of their own preparedness for practice, as well as a reflective journal kept by the lecturer. According to the results, the interventions were well received. Students perceive themselves as having medium to high levels of readiness for the demands of practice. Overall, it was clear that active learning strategies are more effective than traditional instruction methods.

Introduction

As many geotechnical engineers admit, geotechnical engineering is more an art than a science. Critical thinking and engineering judgment are required to solve complex geotechnical engineering problems. Of course, professional engineers accumulate such judgement through experience over time. However, to facilitate the development of these practices within students, it is necessary to create a teaching environment that offers learning opportunities that simulate real-world projects.

To this end, this paper investigates the effectiveness of a suite of pedagogical strategies that were adopted in a geotechnical engineering module within a civil engineering degree program at a South African University. The interventions implemented included various active learning (Christie & de Graaff, 2017) strategies, such as a mini-design project, an invited guest lecture by an industry practitioner, increased use of specific geotechnical software in order to support the mini project, and the composition of a term paper. These interventions formed part of the second cycle of a broader action research project aimed at enhancing student engagement with geotechnical engineering. The first cycle (reported on in Ferentinou & Simpson, 2019, but summarized later in the present paper) revealed a need for greater focus on the development of industry-relevant skills and practices.

The remainder of this paper is structured such that it begins with an overview of existent literature on geotechnical engineering education with a focus on the development of practice-or industry-readiness. Thereafter, it introduces action research as a methodological design, provides an overview of the first iteration of the present action research study, and describes the methods employed in this second iteration. Thereafter, the results of the second iteration are discussed before conclusions, implications and avenues for a future iteration are identified.
Industry-readiness and engineering education

Engineering educators are faced with myriad challenges regarding teaching and learning. In the case of geotechnical engineering education, specifically, the geological processes that occur on the crust of the earth, around which practitioners are required to design structures pose a particular challenge. Moreover, the nature of the geomaterials used as building and/or foundation material offers further complexity. The properties of soils and rocks are contingent upon complex and various factors, including geologic history, tectonic environment, climatic conditions, in-situ stresses, and methods of construction. Because of these complexities, anecdotal evidence suggests that students often find it difficult to conceptualize the particular nature of soils and rocks, and then make the necessary assumptions and idealize the material in order to proceed with the required analysis and design. Moreover, it is common for students to have misconceptions, even about fundamental concepts, such as soil structure for example (Pantazidou, 2009). Students must come to recognize that design does not involve a single correct answer, but rather that it involves a series of decisions built on validation of assumptions and justification of choices made. The open-ended nature of this process often causes discomfort and confusion for students that are focused on achievement of a single correct answer for any given problem, which is common across many general-education and introductory-level courses (Woods, 1994).

Given this need for flexibility and adaptability and the limited opportunity for typical or generic design solutions, significant attention is given in engineering education to the achievement of learning outcomes, such as ‘problem-solving’. This is in part because of the importance of the Washington, Sydney and Dublin Accords in ensuring comparability of programs of study – and engineering professionals – globally. In geotechnical engineering, specifically, Fiegel (2013) has shown how the development of module learning outcomes can have positive effects: improved course organization, more clearly defined expectations regarding student learning, and simplified assessment measures. However, we would argue that such outcomes are not ends in themselves, but should be in service of enhancing the ability of graduates to not only cope with real-world practice, but also to change industry practice for the better.

It is thus necessary to develop pedagogical strategies that expose students to the complexities of real-world geotechnical engineering practice as, in so doing, it becomes possible to facilitate students’ achievement of the required learning outcomes of an engineering program. The literature is replete with examples of such pedagogical strategies. For example, Pierce, Gassman and Huffman (2013: 297) propose a pedagogical strategy they call EFFECTs, which they describe as:

an instructional method to promote [student-centred learning] of fundamental geotechnical principles. This method incorporates elements of realistic context, active learning, and interpretive and reflective writing into an integrated environment. It improves upon shortcomings of traditional didactic methods that lead to shallow learning, specifically in that (1) it gives students opportunities to explore and experience a real engineering problem set in a relevant and meaningful context; (2) active learning opportunities provide motivation to learn how to solve a real problem; and (3) it enables students to discover and prioritize the important concepts for solving that particular problem.

A core element of these pedagogical strategies is students’ active engagement with complex, real-world problems, often presented in the form of project-based learning. For example, the use of mini-projects is employed in Cancela et al (2016) within the context of a chemistry module for engineering students. In that study, the authors describe mini-projects as “an activity carried out in the classroom similar to the activities that exist in real companies” (Cancela et al, 2016: 23). Although they admit that such mini-projects require greater effort
on the part of lecturers, they nonetheless argue that these projects present significant benefit regarding the development of critical thinking and industry-readiness. Project-based learning is similarly used in Kunberger (2013). In that study, the rationale for using projects is that they require “students to synthesise information, perform potentially complex analyses, distinguish between relevant and unrelated material, and justify the reliability of multiple sources of information” (Kunberger, 2013, pg. 266). Furthermore, El-Shamy et al (2013) also report on the integration of real-world engineering applications in the undergraduate geotechnical engineering classroom. In their particular case, students were required to model foundation design using a centrifuge. As the authors explain, the project allowed students to acquire “actual system test data that are similar to field data” thus introducing real-world application of the theoretical concepts taught in class (El-Shamy et al, 2013, pg. 279).

These prior studies aligned with the findings of a first iteration of an action research study undertaken by the authors of the present paper. This action research study is discussed in the section that follows.

An action research intervention

Action research has been widely used in scholarship on teaching and learning in science and engineering (see, for example, Añino et al, 2014; Konstantinou-Katzi et al, 2013; Virkki-Hatakka, Tuunila & Nurkka, 2013). This is because action research is seen as “a suitable research model for engineering educators who wish to do research on active learning in engineering education” (Christie & de Graaff, 2017). Not only is action research “a practical approach to the systematic development of teaching methods”, but it is also useful for “researchers who are interested in studying teaching and learning” (Virkki-Hatakka, Tuunila & Nurkka, 2013, pg. 482).

Action research offers a spiral, or iterative, approach to research in which an identified problem is addressed through consecutive cycles of planning, implementation and reflection (Christie & de Graaff, 2017; Bevins, Jordan & Perry, 2011). A model of action research that resonates with our understanding thereof is that proposed by Bevins, Jordan & Perry (2011) and depicted in Figure 1.

![Figure 1: The action research cycle (Bevins, Jordan & Perry, 2011: 404)](image-url)

In a previous paper (Ferentinou & Simpson, 2019), we described a first cycle/iteration of the present action research study. The initial challenge that we sought to address was a lack of
meaningful engagement on the part of students with the geotechnical engineering course material. To enhance the students' engagement with the course material, a number of changes in the module were implemented in the first cycle: a guest lecture by an industry practitioner was incorporated, more interactive class activities were deployed, weekly quizzes were introduced, and increased emphasis was placed on the use of software applications for solving geotechnical engineering problems. All of these were introduced in addition to the term paper, which the lecturer had already been making use of within the module (in addition to tests and an exam). The results of this initial iteration were positive in that students displayed greater satisfaction with the course and, based on the teaching evaluations and lecturer reflections, also engaged with the course material more meaningfully.

However, what emerged in this initial iteration was a need to link the activities and course materials more closely to the demands of practice. It was evident that students struggled to link the course materials to the broader concerns of geotechnical engineering practice, and that they had difficulties dealing with complex problems that more closely resembled those likely to be encountered in practice. Given this, and based on the literature presented in the preceding section of this paper, it became evident that, in addition to the interventions introduced as part of the first iteration, there was also a need to link student learning to engineering practice through the use of project-based activities. To this end, students were assigned a project which required them to undertake design for a commercial development with poor geotechnical conditions (the introductory section of the assignment brief is presented as an appendix to this paper).

Data collection and analysis

This research was undertaken within a module on geotechnical engineering undertaken in the third year of a four-year degree in civil engineering. The module was completed over 14 weeks. Table 1 summarises the development of the module through the two iterations of the present action research project. As can be seen, the outcomes of the module have remained the same. However, in the first iteration of the project, specific attention was given to classroom activities in order to foster greater engagement with the module content on the part of students. While these efforts were successful (see Ferentinou and Simpson, 2019), they revealed a need for enhanced assessment practices that more closely resemble the demands likely to be placed on students after graduation; as such, in the second iteration, greater attention was given to assessment practices.

In order to assess the effect of these changes to the module, the students were asked to complete an anonymous, paper-based survey pertaining to their perceptions of their own industry-readiness. The survey interrogated the students' perceptions regarding the contribution that the term paper (included in the module from before the inception of this action research project), the guest lectures by industry practitioners and use of software (introduced in the first iteration of the action research project), and the mini-design project (a new addition as part of this, the second iteration) had made to their preparedness for the demands of geotechnical engineering practice. In this way, we hoped to be able to isolate the particular impact of the various interventions regarding developing students' preparedness for industry.

The questionnaire was completed during a class towards the end of the semester, and included five questions where students had to select one among several predefined answers. No demographic information pertaining to the students was collected, as the entire class was invited to participate in the survey and, as such, it was felt that the participants were broadly representative of the student population. Instead, these questions were formulated in order to ascertain the students' own perceptions of their level of preparedness to join industry. The first question asked students to rate their preparedness to enter a career in the field of geotechnical engineering, having completed the coursework (but not the exam) in the third year of the civil engineering degree programme. It should be noted that students had not yet
undertaken the fourth year geotechnical engineering module. Four options were available to students: High (with the explanation of: I’m ready to start my career tomorrow), Developing (explained as: I feel that with mentorship and guidance, I’m ready for the world of work in this area), Limited (explained as: if pressed, I could make it work, but I don’t feel confident in my readiness to enter a career in this field), and Low (I am unprepared for entering into a career in geotechnical engineering).

Table 1. Development of the geotechnical engineering module through two action research cycles

<table>
<thead>
<tr>
<th>Outcomes</th>
<th>Initial module design</th>
<th>1st iteration</th>
<th>2nd iteration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Understand how soil may be modelled</td>
<td>Understand how soil may be modelled</td>
<td>Understand the method of operation of standard laboratory testing apparatus and derive strength and stiffness properties</td>
<td></td>
</tr>
<tr>
<td>Understand the method of operation of standard laboratory testing apparatus and derive strength and stiffness properties</td>
<td>Calculate the stresses induced beneath shallow foundations and the resultant foundation settlement using elastic solutions and consolidation theory</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Calculate the stresses induced beneath shallow foundations and the resultant foundation settlement using elastic solutions and consolidation theory</td>
<td>Use limit analysis and limit equilibrium techniques to determine the limiting lateral earth pressures acting on retaining structures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Use limit analysis and limit equilibrium techniques to determine the limiting lateral earth pressures acting on retaining structures</td>
<td>Determine the stability of slopes</td>
<td>Determine the stability of slopes</td>
<td></td>
</tr>
</tbody>
</table>

Classroom practice

Largely lecture-based and teacher-centred

Greater attention given to student-centred teaching and active learning; Guest lecture by industry practitioner; Increased use of software in practical sessions – demonstration through tutorial sessions

Greater attention given to student-centred teaching and active learning; Guest lecture by industry practitioner; Increased use of software in practical sessions - demonstration through tutorial sessions

Semester-based assessments

Tests (70%) Term Paper (30%)

Tests (50%) Term Paper (30%)

Assignments (15%) (student solve problems both analytically and numerically using specific software)

Assessments (10%) (student solve problems both analytically and numerically using specific software)

Assignments (10%)

Quizzes (5%)

Quizzes (5%)

Mini-design project (20%)

The other four questions focused on the specific value of each of the interventions mentioned above (the term paper, the guest lectures, increased use of software, and the mini-design
project). Students could characterise each specific activity as having contributed “a lot”, “a fair bit”, “minimally”, or “not at all” to their own preparedness for practice. For all five questions, students were invited to explain their answer by way of an open-ended follow-up question.

In addition to the questionnaire data, we also continued to rely on reflection as an important input within the action research cycle. This is in line with literature on action research (see, for example, Brydon-Miller, Greenwood and Maguire, 2003), as well as our findings during the first iteration of the project (see Ferentinou & Simpson, 2019).

In total, 65 students completed the questionnaire, but only between 54 and 60 students answered each question, which represents around 50% of the entire class. The remainder either were absent from class when the survey was completed, or chose not to complete the survey, an option that was made available to them without penalty. The data obtained was analysed by obtaining frequency counts for the five Likert-scale type questions. The students’ open-ended responses were categorised within themes and the most commonly occurring themes were then identified.

**Presentation of results**

Table 2 shows the frequency of occurrence of responses to the first question, which asked students to rate their overall level of preparedness. It also presents the results of the thematic analysis of the students’ responses to the request for elaboration. Only the most commonly emergent themes are summarised in the Table.

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Answer</th>
<th>Summary of most common explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>High</td>
<td></td>
</tr>
<tr>
<td>23</td>
<td>Developing</td>
<td>Understand the concept; acquired knowledge; work done during the semester helped; key concepts introduced; solved real life problems But more practical experience and work would be necessary as well as mentorship and guidance through the first steps</td>
</tr>
<tr>
<td>27</td>
<td>Limited</td>
<td>No link between theory and practice; two students reported limited field experience, not enough clarity</td>
</tr>
<tr>
<td>10</td>
<td>Low</td>
<td>Lack of practicals; no connection between class teaching and industry requirements based on the site visit; difficult module</td>
</tr>
</tbody>
</table>

Table 3 summarises the results obtained from the remaining questions. These questions asked students to rate the contribution made by the term paper, the guest lectures, the use of software and the mini-design project to their perceived preparedness for the demands of practice. It should be noted that the term paper had been included as part of the module since before the inception of the broader current action research project, while the use of software and inclusion of guest lectures was introduced in the first iteration. The mini-design project was introduced as part of the second iteration of the action research project and was specifically aimed at simulating a real-world problem (see the introduction to the project brief presented as an appendix to this paper).
### Table 3. Students’ perception of the contribution of a term paper, guest lectures, use of software, and a design project to their own industry-readiness

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Answer</th>
<th>Summary of most common explanations</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>a lot</td>
<td>writing reports a very useful skill; directly linked to real life scenarios</td>
</tr>
<tr>
<td>31</td>
<td>a bit</td>
<td>left comfort zone and learned about something that is not part of the topics taught in class; developed time management; exposure to research and creativity; exposure to new knowledge; generated awareness of the problems faced in industrial sites</td>
</tr>
<tr>
<td>14</td>
<td>minimally</td>
<td>need more information on the subject; brief introduction to relevant topics; fun research activity; acquired research and report writing skills</td>
</tr>
<tr>
<td>2</td>
<td>not at all</td>
<td>lack of guidance</td>
</tr>
<tr>
<td>11</td>
<td>a lot</td>
<td>learned to work with fellow group members; real-life project; theory and practical modelling</td>
</tr>
<tr>
<td>26</td>
<td>a bit</td>
<td>exposure to problems faced on site; not enough information provided; difficult to understand what needed to be done at first but this became clearer; enabled thinking about real life situations in an analytical way</td>
</tr>
<tr>
<td>12</td>
<td>minimally</td>
<td>problem wasn't clearly stated; too many assumptions</td>
</tr>
<tr>
<td>7</td>
<td>not at all</td>
<td>project requirements not explained properly; project was not clear enough</td>
</tr>
<tr>
<td>26</td>
<td>a lot</td>
<td>basics learned in class implemented in industry; guest lecturer elaborated on what happens in industry</td>
</tr>
<tr>
<td>20</td>
<td>a bit</td>
<td>great motivation; intriguing; exposure to new technologies</td>
</tr>
<tr>
<td>6</td>
<td>minimally</td>
<td>good insight about the industry; a great experience</td>
</tr>
<tr>
<td>2</td>
<td>not at all</td>
<td>could not attend</td>
</tr>
<tr>
<td>15</td>
<td>a lot</td>
<td>software was self-study; very useful</td>
</tr>
<tr>
<td>28</td>
<td>a bit</td>
<td>greater confidence and independence regarding software; an advantage in industry</td>
</tr>
<tr>
<td>10</td>
<td>minimally</td>
<td>lack of understanding of how to use the software</td>
</tr>
<tr>
<td>2</td>
<td>not at all</td>
<td>software rarely used</td>
</tr>
</tbody>
</table>

### Discussion and conclusions

According to the responses received, a number of patterns are worthy of discussion.

Firstly, a great majority of the students positively experienced the designed teaching and learning interventions, and there was general agreement that the designed activities increased their engagement with the module and contributed to them feeling prepared for possible future practice in geotechnical engineering. Many students argued that the designed activities provided them with a foundation to build on, but that more practice and exposure to real-world problems would be required for them to increase their knowledge, experience and preparedness for industry.
However, several students continued to comment on a lack of connection between theory and practice and the need for more practical experience. This was particularly evident in students’ responses to the first question, which required them to reflect on the module as a whole rather than any one particular teaching and learning activity. We note that it is necessary to conduct further investigation regarding what students believe will provide the necessary practical experience, or the required connection between theory and practice. Some of the students’ comments suggest that the students identify a need for work-integrated learning opportunities. However, this is unreasonable to expect within a standard module, where the contact hours are predefined by the allocated program credits, and are constrained by the timetable and other logistics. As such, at least within the current curriculum design approach there is limited opportunity for technical visits and no provision made for work-integrated learning. Also, it appears that students neglect to consider the important role that the candidacy phase plays in providing the necessary work experience. This is evident in the fact that none of the students mentioned this in their responses.

Interestingly – and somewhat curiously – the students’ responses to questions pertaining to specific teaching and learning activities were much more positive than they were when considering the module as a whole. The students’ responses were positive to very positive regarding all of the individual teaching and learning interventions.

The students were most positive about the inclusion of a guest lecture by an industry professional, the focus of which was on the future of engineering practice and the necessary skills required of geotechnical engineers if they are to remain relevant through the fourth industrial revolution and beyond. The students’ responses were also particularly positive regarding the use of software, although many students – rightly so – argued that the module had only provided a basic introduction to the use of software applications and that there was much more to learn in this regard through practice in the future.

Students were less positive (but still positive, overall) regarding the contribution of the term paper and the mini design project. Contrary to what we had hoped and expected, students were least positive regarding the mini design project, identifying it as making the smallest contribution to their industry- or practice-readiness. However, the reasons they provided for this are interesting to note. Many students found the design task confusing and that the brief lacked information. In many instances, students noted that the more they worked on the design project, the more they understood what was required. The students rated the mini design project as contributing little to their industry readiness, but explained their reasoning in terms of the difficulties they experienced in completing the project. However, these difficulties were exactly the reasons that informed the decision to include such a project in the module. The characteristics of the project as assessment were that it was technical in nature, and that it required a solid foundation in and understanding of the content that was covered during the semester as well as that covered in a previous module the semester before. As such, we argue that the explanations that the students offer (that the problem is not clearly stated, that too many assumptions had to be made, that the problem requirements were vague, and so on) are exactly the reasons why such a project does serve to prepare students for what they might experience in practice.

**Implications and future study**

As shown above, the student responses suggest an overall positive experience of the designed teaching and learning activities implemented as part of the current action research project. Moreover, where some students expressed dissatisfaction with activities, this was largely because they either did not participate in the activity or found the activity task challenging. As such, it is evident that students confuse their discomfort with challenging tasks and their own preparation for future practice. Challenging tasks, with vague requirements that necessitate use of engineering judgement, are the kinds of tasks that prepare students for the demands of industry. As such, teaching and learning for practice-readiness requires that students enter a space of discomfort in order to develop engineering
judgement, independent learning, and critical thinking. This is an important finding of this study, and could be taken up by other engineering educators.

One aspect that emerged repeatedly in the lecturer’s reflections during this second iteration of the action research project was the need to introduce more direct tools for “observing” geotechnical engineering activity, such as the use of physical models or augmented reality. Students appreciated the use of software to undertake geotechnical engineering work, but technologies can also be used to provide access to the knowledge of the geotechnical engineering discipline. For example, El-Shamy et al (2013), in their study using geotechnical centrifuge model testing, argue that such modelling provides a valuable tool to the geotechnical engineer, enabling the physical study and analysis of design problems by using geotechnical materials. However, there are other avenues for the modelling of geotechnical engineering phenomena: from low-tech, purpose-built physical models to high-tech modelling software that draws on augmented or virtual reality. As such, future iterations of this ongoing action research study may focus more specifically on the use of modelling to enhance student engagement with geotechnical engineering as well as introduce them to the complexities of practice in this area.

Finally, the methodology used in this paper offers rich potential for application within engineering education research. A further contribution of the present paper is its consideration of pedagogical avenues for teaching engineering judgment and critical thinking, which are of increasing interest and importance to engineering educators.

References


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Appendix: Except from design project brief

Problem Definition

Privately owned retail, commercial and residential developments require the optimisation of retail space versus cost of realising the space. A project in point is a commercial development on marginal land – challenging topography, poor founding conditions and poor in-situ materials – whereby large fill platforms were proposed to create space for retail and commercial developments, i.e. office blocks and shopping centres along the boundary of the development. The property developers required the respective platforms to be constructed with minimal cost as possible but to maximise the platform surface area. To maximise the platform area, the batter angle of the fill would need to be increased to an optimal point to realise then necessary space but to ensure long time stability and serviceability.

This problem requires that in-situ materials from elsewhere on the site (it may be assumed that this consists of Berea Formation sands, similar to those revealed by the foundation investigation – see below) be utilised to construct the 15 – 17 m high fill platforms, as hauling and disposing of any poor materials would introduce substantial costs. Therefore, the key question: what is the maximum batter angle, α, that the fills can be constructed at in order to maximise the platform surface area which sells for β Rand per square metre using poor in-situ materials that need to be reinforced with geosynthetics that cost γ per unit length/square metre. Would geosynthetics be necessary? How would you incorporate the effect of groundwater?

In this analysis, it is important to consider/carry out:

- A deterministic analysis under Ultimate limit State condition;
- A probabilistic analysis;
- A Serviceability Limit State analysis to evaluate long term settlement of structures mainly 2 and 3 storey building) to be constructed atop the fills, and;
- Practicalities, such as re-vegetation of the slopes, drainage etc.
Academic SUCCESS: An analysis of how non-cognitive profiles vary by discipline and year for engineering and computer science students

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Abstract: Most universities in the United States use some combination of high school academic performance along with standardized test results as the basis for admission decisions. These criteria alone are poor predictors of academic success for students studying engineering and computer science. The Studying Underlying Characteristics for Computing and Engineering Student Success (SUCCESS) survey measures non-cognitive and affective (NCA) competencies in students with the goal of seeing how these factors play a role in predicting the academic success of these students. Two questions asked as part of the SUCCESS project include: 1) How do NCA profiles vary among engineering and computer science majors? 2) How do these profiles change over time? Using
student responses (n=356) from a large public university in the western United States, we present how these profiles compare across engineering and computing majors and how cross-sectional data for students in different years of study give us an early, albeit imperfect, view of how NCA profiles change over time.

Introduction

Most universities in the United States use some combination of high school academic performance in the form of a grade point average (GPA) along with standardized test results such as the SAT or the ACT as the basis for admission decisions (Camara and Kimmel, 2005). The tests attempt to measure cognitive ability; however, it is known that alone, they are poor predictors of academic success for students studying engineering and computer science (see Zhang et. al., 2004). We posit that non-cognitive and affective (NCA) competencies (attitudes, habits and beliefs) can play a large role in predicting students' academic success. Thus, we developed the Studying Underlying Characteristics for Computing and Engineering Student Success (SUCCESS) survey to examine the NCA competencies relevant to success for engineering and computer students (see Berger et al., 2018). The survey measures 24 NCA factors and is comprised of 14 available and validated assessment tools that measure Big 5 personality, Community, Grit, Thriving, Identity, Mindset, Motivation, Time and Study Environment, Test Anxiety, Perception of Faculty Caring, Self-Control, Stress, Gratitude, Belongingness and Mindfulness. Berger et al., (2018) describes the collaborative nature of the survey construction and Scheidt et al. (2018) performed an exploratory factor analysis of the different constructs and found acceptable validity for the items used in a pilot version of the survey. Further analysis of the data shows that SAT may predict only about 10% of the variance in students' self-reported GPA, while a group of 10 NCA factors taken together predict 26% of this variance (see Scheidt, Senkpeil et al., 2018). Of these 10 factors, seven (see Table 1) are considered malleable and therefore might be changeable through specifically designed educational initiatives.

For the subject of this study we are looking at students at a large Western U.S. university known for its engineering and computer science programs. We are seeking to answer two questions: 1) How do NCA profiles of these important malleable constructs vary among engineering and computer science majors for students at this university? 2) How do these construct measures change over the students' time at the institution? The goal is to understand how specific or combinations of NCA factors might predict success for these students and perhaps more importantly how some of these factors might be altered in students to improve their experience and ultimately their success. Differences in profiles among majors could potentially require the design of discipline specific initiatives to bring about desired change.

Background

Using SUCCESS Survey data from two institutions (n=490), Scheidt, Senkpeil et al. (2018) showed that standardized test scores (SAT and ACT) account for only 10.26% of the variance in engineering and computer science students GPA thus calling into question the use of these as predictors for success. Meanwhile 26.37% of the variance in GPA can be explained by looking at the combined contributions of 10 NCA factors measured in the SUCCESS survey. Of these 10, seven are considered malleable, providing an opportunity for using carefully designed initiatives to change these beliefs, behaviors or attitudes in students to help them succeed. Table 1 lists these seven constructs along with their individual prediction of GPA variance (not taken together as a group).

Next, we provide a brief description of each of the seven malleable factors measured that most significantly contribute to the variance in GPA in the SUCCESS survey, how they are related to student success and how they may be changed in students. Note that survey
respondents rated each item on a seven-point Likert scale. For reference, Scheidt et al.
(2018) list all the survey questions in the SUCCESS instrument.

Table 1: Contribution to Variance in GPA

<table>
<thead>
<tr>
<th>Malleable NCA Factor</th>
<th>$sr^2$ [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motivation (Expectancy)</td>
<td>17.82</td>
</tr>
<tr>
<td>Time and Study Environment</td>
<td>11.09</td>
</tr>
<tr>
<td>Test Anxiety</td>
<td>7.54</td>
</tr>
<tr>
<td>Perception of Faculty Support</td>
<td>7.38</td>
</tr>
<tr>
<td>Grit: Perseverance of Effort</td>
<td>7.24</td>
</tr>
<tr>
<td>Engineering Identity: Performance Competence</td>
<td>7.14</td>
</tr>
<tr>
<td>Stress (Frustrations)</td>
<td>4.46</td>
</tr>
</tbody>
</table>

**Motivation: Expectancy**

To measure motivation in students, the SUCCESS survey uses a Future Time Perspective to
measure five constructs (expectancy, connectedness, instrumentality, value and perceptions
of the future). Of these, the best predictor of the variance of engineering and computer
science students' GPA is the expectancy construct. This construct, derived from Eccles
Expectancy-Value Model (see Eccles and Wigfield, 2002) assumes that one’s expectancies
and values directly influence one’s task choice, persistence and performance. Five survey
items validated by Kirn and Bensen (2015) such as “I expect to do well in my engineering
classes,” and “I am certain I can master the skills being taught in my engineering classes”
measure the construct. Responses were scaled from 1 (strongly disagree) to 7 (strongly
agree).

Matusovich et al. (2010) found that engineering students with higher expectations have
higher academic performance; moreover, these students persist longer on tasks if they
perceived a higher value for that task. Finally, instructors can foster motivation in students by
tying coursework to future goals and encouraging students to believe they can succeed. The
malleability of motivation in engineering and computer science students (see Ponton et al,
2001) along with its apparent importance in student academic makes this construct an
important one to monitor throughout a student’s academic career.

**Time and Study Environment**

This scale is one section of the Motivated Strategies for Learning Questionnaire (MSLQ)
(Pintrich, et al., 1991) that seeks to evaluate a student’s ability to manage time and regulate
study environments. Included in this measure is a student’s level of organization, scheduling,
and planning. Time management can range from setting aside a night for studying to weekly
and monthly scheduling. Study environment refers to the setting where the student studies
for class work. The ideal study environment for a student is organized and free from
distractions. The time and study environment section of our survey includes eight items,
using the same Likert-scale as test anxiety. A higher score corresponds to better time
management and use of study environments by the student, which is one of the more
strongly correlated MSLQ measurements to better academic performance.

Credé and Phillips (2010) studied how MSLQ traits are related to GPA. They found that time
and study environment had one of the highest correlations to grades. They also found that
students high in this trait might have a better ability to engage in self-regulated learning.
Perhaps because they find meaning and purpose in their tasks, they self-monitor, and have
high levels of self-efficacy. All of these traits together can contribute to higher academic
success. This is extremely important as this suggests that properly motivating students could
encourage them to pursue better learning strategies, in turn improving their success. Hattie et al. (1996) found structural aids, like written planning and practicing task strategies, to be very effective at interventions aimed to improve performance.

**Test Anxiety**

The Test Anxiety Scale is another construct included in the MSLQ (Pintrich, et al., 1991). It was created to measure students' worries, which can hinder performance (cognitive component) and physiological arousal aspects of their anxiety (emotionality component). There are five items to evaluate test anxiety. For example, a two of these items are "When I take tests, I think of the consequences of failing" and "I have an uneasy, upset feeling when I take an exam." The questions are scaled to a Likert-scale with anchors of 1, not true of me, to 7, very true of me. A higher average score corresponds to greater test anxiety.

Increased stress is a common experience for many students taking academic exams. Rates can range from 25-40% of students having test anxiety, and multiple studies (see Putwain, 2007 and Carter et al., 2008) show there are higher rates of test anxiety for females and racial minorities. A more recent study, Bellinger et al. (2015), found similar results with females having higher test anxiety scores than males. In addition, Bellinger et al. (2015) found higher test anxiety correlates to lower exam scores for both male and female students in engineering.

**Perception of Faculty Caring**

The perception of faculty caring scale (see Hoffman et al, 2002) measures both student’s perception of the empathy provided by faculty members and the student’s perception of faculty support and comfort. Although the two are correlated, the perception of faculty support scale contributes significantly to the variance in engineering and computer science student GPA and is addressed here. The scale is measured using four questions such as "If I had a reason, I would feel comfortable seeking help from a faculty member outside of class time (i.e. during office hours, etc.)" and "I feel comfortable talking about a problem with faculty." Responses were scaled from 1 (strongly disagree) to 7 (strongly agree).

Pascarella and Terenzini (1980) found a very strong contribution of student-faculty relationships and faculty concern for students to the retention of students in a program. Given the sometimes-low retention rates in engineering and computer science, this is of notable interest. Similarly, Zumbrun et al. (2014) found that students’ perception of instructors’ social as well as academic support are positively associated with student feelings of belonging. These feelings in turn correlate with motivation and academic success. Student perceptions of how the faculty care can change over time and can be impacted through interventions (see Walton and Cohen, 2011). In summary, the perception of faculty support correlates to student success and can change throughout a student’s time in school.

**Grit: Perseverance of Effort**

This construct was proposed by the psychologist Angela Duckworth and is defined as the passion and perseverance for long-term goals (Duckworth et al., 2007). Grit is usually unrelated or inversely related to intelligence or talent. The two subcategories of grit are consistency of interest and perseverance of effort. The Grit-S (short grit scale), which is comprised of eight items, was used in this study. Reduction of items from Grit-O (original grit scale) to Grit-S was shown to maintain predictive validity. For the SUCCESS survey, we scaled each item with anchors of 1, very much like me, and 7, not like me at all. Higher scores indicate a higher level of grit.

Grit is an important trait in students because it relates to their effort and persistence in their studies. Perseverance of effort is a superior predictor of GPA while consistency of interest is a better predictor of number of lifetime career changes (Duckworth and Quinn 2009). Undergraduates who scored higher in grit earned higher GPAs than their peers despite having lower SAT scores (Duckworth et al., 2007). Grit may could be a better predictive
factor of student success than some standardized tests. Being a relatively new construct, its malleability is unknown, although efforts are being undertaken to alter this trait.

Engineering Identity: Performance Competence

Based on the identity theory approach to commitment by Burke and Reitzes (1991), Godwin (2015) developed and validated a set of instruments to measure three aspects of Engineering identity, including recognition, interest and performance competence. Of these three, performance competence accounted for a significant amount of the variance in engineering and computer science student GPAs in the pilot run of the SUCCESS survey. Performance competence is measured using six items such as “I am confident that I can understand engineering outside of class,” and “I understand concepts I have studied in engineering.” Responses were scaled from 1 (very inaccurately) to 7 (very accurately). Higher scores indicate that students have a greater sense of identity to their engineering or computer science major.

Engineering identity is a significant indicator of educational and professional persistence (see Pierrakos et al, 2009) for engineering students. In addition, engineering identity develops and changes over time. One study by Godwin and Lee (2017) showed that engineering identity became weaker for second year students and increased to its highest for 4th year students. Engineering identity can be promoted in subtle and simple ways. For example, instructors can refer to students as “engineers” rather than “engineers in training” to improve engineering identification. Other ways to promote engineering identity are through active learning and the selection of projects undertaken by students. The ability to increase performance competence is a rich opportunity to increase student success.

Stress: Frustrations

The Student Life-Stress Inventory (see Gadzella et al, 2004) is a validated instrument that measures both stressors in student life and reactions to those stresses. Included in the SUCCESS survey is the instrument to measure a student’s frustrations with not meeting goals which contributes significantly to the variance in engineering and computer science student GPAs. Student stress due to frustrations is measured using items such as “I have experienced frustrations due to delays in reaching my goals,” and “I have experience daily hassles which affects me in reaching my goals.” Responses were scale form 1 (not at all) to 7 (very much so). Higher scores indicated that students experience more stress due to frustrations in achieving their goals.

Stress can affect student academic performance both positively and negatively. Various coping mechanisms and initiatives can help students improve academic performance when under stress (e.g. Lumley, & Provenzano, 2003). Improved time management skills and Mindfulness-based stress reductions can also reduce stress.

Methods

We collected pilot data via a Qualtrics™ surveys at a large public western U.S. university known for its engineering and computer science programs in the spring of 2017. To encourage participation, students completing the survey were entered into a raffle with the opportunity to win a gift card. Prior to analysis, all personally identifiable information was removed from the data and incomplete surveys and those where the student did not answer a validation question correctly were eliminated leaving a total of 356 participants. Figure 1 below shows the breakdown of student responses by discipline. Table 2 gives the breakdown by year in school. This cross-sectional data gives us a glimpse as to how NCA factors may be changing by year in school through the experiences students have during their time at University. A more thorough longitudinal study of participants NCA profile is ongoing through the repeated administration of the survey over multiple years and will be reported in the future.

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In order to determine whether there is a difference in NCA profiles between majors (Computing, Civil, Electrical and Mechanical) or cross-sectionally across years in school, an analysis of variations (ANOVA) was performed using the Statistical software R (R Team, 2017). The ANOVA tested for differences in mean values of each of the seven specified NCA variables across predictor variables year-in-school and major. We opted to run multiple univariate ANOVA tests as opposed to a MANOVA test for each response. This is because we are curious about each factor’s dependency on major or year in school independently, as opposed to whether there are any overall effects of major or year in school. For each predictor, this is a total of seven tests, looking at motivation by expectancy, time and study environment, test anxiety, perception of faculty support and comfort, grit in terms of preservice of effort, engineering identity in terms of performance competence, and stress from frustration. To adjust for multiple hypothesis tests, a Bonferroni adjusted significance level of 0.05/7 = 0.00714 was used (for an overall error rate of 0.05). This means the probability of making at least one false discovery is capped at 5%. We also considered the Benjamini and Hochberg false discovery rate algorithm, which adjusts the significance level of each test according to its p-value’s rank among all tests. There are no contradictions between these two adjustment methods.

**Results and Discussion**

Looking at how NCA factors vary for students in different years at university, only one of the tests yielded significant results at the adjusted significance level. There is strong evidence (p-value = 0.000998) that the perception of faculty support differs across year in college (Fig. 2). On average, second-year students have significantly lower scores for perception of faculty support than two of the other groups, with estimated differences from first and fourth+ years of 0.67 and 0.54 points respectively. This drop in perception of faculty support may have implications for student performance as high perception of faculty support has been correlated to increased student success. This result also demonstrates a window of opportunity to improve student success and outcomes. In addition, there is evidence at the individual 5% confidence level that motivation by expectancy differs across year in college (p-value = 0.0275). However, this test is not significant at the Bonferroni adjusted 0.00714.
level nor at the Benjamini and Hochberg adjusted 0.01429 level. Because these adjustments are known to be conservative, we looked more closely at this model. Looking at the boxplots of motivation by expectation across years in school (results not shown), it is apparent that motivation is lowest among third years (though it does not rise to statistical significance). There are no significant differences between any other groups (see Table 3 for all ANOVA results).

Looking at how NCA factors vary through year in college, we found that there were no significant differences. This is somewhat surprising in that, as faculty and as an institution, it would seem obvious that our goals are to help students develop competence as engineers, which not only includes technical competence but whole-person competence, including these NCA factors. This lack of variation or growth across the years, while somewhat dispiriting, again represents a great opportunity for engineering faculty and colleges to help students succeed. We close with a caveat on this finding: Our examination of how the NCA profiles change over time is cross-sectional and, as such, has limitations. For example, at this point, we do not have evidence that students who are farther along in college continue to interpret the survey questions the same. Additionally, we acknowledge that engineering programs generally have high attrition rates. We do not know if the overall response patterns of the students in higher years is different, or if students who responded in certain ways to the survey have left engineering and are no longer available. Therefore, our cross-sectional analysis may not be capturing changes in student responses, but potentially changes in student population.

![Figure 2: Perception of faculty support by year](image)

<table>
<thead>
<tr>
<th>NCA Factor</th>
<th>ANOVA by Major</th>
<th>ANOVA by Year</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motivation (Expectancy)</td>
<td>0.044*</td>
<td>0.028*</td>
</tr>
<tr>
<td>Time and Study Environment</td>
<td>0.452</td>
<td>0.312</td>
</tr>
<tr>
<td>Test Anxiety</td>
<td>0.036*</td>
<td>0.093</td>
</tr>
<tr>
<td>Perception of Faculty Support</td>
<td>0.162</td>
<td>0.001**</td>
</tr>
<tr>
<td>Grit: Perseverance of Effort</td>
<td>0.507</td>
<td>0.181</td>
</tr>
<tr>
<td>Engineering Identity: Performance Competence</td>
<td>0.151</td>
<td>0.072</td>
</tr>
<tr>
<td>Stress (Frustrations)</td>
<td>0.864</td>
<td>0.814</td>
</tr>
</tbody>
</table>

* significant at individual 0.05 level  ** significant at adjusted 0.00714 level
Summary and Future Work

In this work, we presented some preliminary results for seven constructs in the SUCCESS survey which is being used to predict student success in engineering and computer science. The seven constructs were selected as they have been shown to predict the variance in student’s GPAs and they are malleable, meaning that it may be possible to design initiatives that lead to changes in these attitudes and behaviors which can lead to better academic success. From this small dataset we see that for a large western U.S. University, the perception of faculty support fell during the second year of study and slowly rose back to the freshmen level after two years. The cause of this will require further study. We also saw that by and large the other six constructs do not vary across the four-year curriculum of the engineering and computer majors or are different between majors. Since there are at present no major organized initiatives at the university to address these student beliefs and attitudes, these results may indicate an opportunity to create those and promote higher success rates. The next steps in the project are to look more carefully at which constructs in the survey correlate with a broad definition of student success and create validated initiatives (a.k.a. interventions) to increase the positively correlated factors in engineering and computing students. Our final goal is to provide environments, pedagogy and support that leads to improved success for engineering and computing students.

References


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Motivations and Offline Experience in a Blended STEM MOOC

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Abstract: STEM MOOCs differ from traditional STEM classes in several key ways. As instructors seek to improve these courses, additional research is needed on students’ complex motivations to take these courses and ways to incorporate hands-on learning. This paper presents findings from the study of a neuroscience MOOC that covered electrical engineering principles and an at-home lab kit that connected concrete applications to complex neuroscience processes. This paper uses thematic analysis of over 50 interviews to understand student motivations and their offline behaviours, including their interactions with the lab kit. Overall, student motivational profiles fit into a small number of clear groups and subgroups, including teachers, professionals, and students. Students used the lab kits to expand their learning through both offline and online interactions. Future STEM courses may use these findings to structure their course based on student motivation or encourage additional online and offline engagement using the lab kits.

Introduction and Context

Massive Open Online Courses (MOOCs) offer extensive data that record students' every click and interaction. This large data source can offer a wealth of nuanced educational data on each individual student as well as on whole populations of students. However, this environment also comes with unique challenges. MOOCs offer an open environment where students often enter and leave based on their own goals. This free flow of students causes both attrition and enrolment to take on a very different meaning (DeBoer, Ho, Stump, & Breslow, 2014). In this environment, understanding the varied motivations of students can give a more accurate picture of this flow and inform designers on ways to create more student-centred online spaces. Such student-centred environments have been found to correlate with higher motivation and higher self-efficacy (Cornelius-White, 2007) In the environment of Science, Technology, Engineering, and Mathematics (STEM) MOOCs, additional challenges exist. To learn complex subjects, most traditional STEM classes employ hands-on labs (Furtak, Seidel, Iverson, & Briggs, 2012). In a solely-online context, hands-on labs seem unfeasible. Yet, the absence of these experiences may be why online STEM courses have shown lower understanding of concepts and a higher likelihood of
misconceptions (Wendt & Rockinson-Szapkiw, 2014). Hands-on labs in MOOCs have remained largely unstudied, as few STEM MOOCs offer such components. Moreover, such at-home experiences would not be directly reflected and measurable in the online platform’s clickstream data.

A small number of MOOCs have tried to incorporate remote, virtual, or physical experiences in conjunction with the online experience. This course was one such MOOC, as it incorporated a physical at-home lab kit that offered unique affordances to study the use of offline materials within a STEM MOOC. This MOOC used electrical engineering principles to teach science concepts. Fundamentals of Neuroscience is a MOOC offered from an elite university in the northeast United States. This course examined synapses and used electrical engineering concepts to demonstrate the function of these synapses. This course offered students the opportunity to learn basic neuroscience principles through classroom lecture videos, interactive videos that asked students questions to reinforce understanding, online labs that allowed students to manipulate variables, do-it-yourself lab videos, and a final exam used to determine students’ final grade in the course. Electrical engineering experiments were completed via an at-home lab kit by those students who had a kit (see data collection section). These simple at-home experiments taught about action potentials through the use of a Backyard Brains Spiker Box and various experiments on cockroaches and worms.

Data were collected on student behaviours in this course through clickstream data of all participating students, and, for a limited sample of respondents, data were collected on student motivations through pre- and post-course surveys. Previous research has examined the clickstream data, but these data only allow researchers to determine what students are doing while on the course website (Atiq, Chen, Cox, & DeBoer, 2015; DeBoer, Xin, Atiq, Oertelt, & Cox, 2015; Haney, Atiq, DeBoer, & Cox, 2016). Behaviours completed on the at-home lab kit were not recorded in the clickstream data, as the kits are entirely offline. While some information on student motivations was available in pre and post surveys, students could only rate limited options to show their motivations. Understanding more nuanced motivations and impact of these motivations on behaviours necessitates a different approach.

**Research Questions**

Clickstream data only shows the online behaviors of students within the course site. Yet, student engagement is more nuanced. Motivations impact student engagement with online materials as their offline behaviors supplement student learning. These two aspects create a more nuanced picture that is impossible to explore solely via clickstream information. Thus, this paper examines student motivation and offline behaviors, specifically their utilization of the lab kit. In particular, we study students’ qualitative motivation for course participation and engagement, their stated reasoning for engaging in both online and offline behaviours, and their course experience, including the offline experience. We address the following research questions:

1. What motivates students to take this course, and how does their motivation(s) inform their engagement?
2. How did students utilize an offline tool built for integration in an online course? Specifically, how do they use the lab kit and why?

**Literature Review**

Student motivation in MOOCs can be gathered in multiple ways, but most often is measured through a question that offers a choice between potential reasons for enrolling in the course or motivation scales such as Pintrich’s (1990) self-efficacy and self-concept scales. Often, motivation questions in MOOC surveys offer only a few options. For instance, one university uses a multiple choice question with seven different reasons to study that students can select
from including: to get a certificate, learn new things, improve my career options, meet new people, try online education, see what MOOCs are, and browse the college’s offerings (Macleod, Haywood, Woodgate, & Alkhatnai, 2015). In contrast, Pintrich’s motivation scales seek to place values on how students’ views impact their strategies for learning. These scales build on the expectancy-value model of motivation, which connects self-regulated learning to students’ beliefs of their abilities, students’ beliefs about the importance of the task, and students’ emotional reaction to the task. The scales are compiled into the Motivated Strategies for Learning Questionnaire (MSLQ), which uses statements that students rank using a Likert scale (Pintrich & De Groot, 1990).

Motivations to enrol in a MOOC have been shown to vary. One study found that at least 70% of MOOC learners they studied were taking MOOCs in a subject area that differed from their original studies (Macleod et al., 2015). In one MOOC offered by a prestigious university, under 10% of students enrolled for employment or job advancement, while 25% of students enrolled as a personal challenge; these motivations were not found to affect performance in the MOOC (Breslow et al., 2013). Yet, performance itself is often an issue in MOOCs as many students are not interested in course grades, course completion, or other traditional measures of achievement (DeBoer et al., 2014). This view is reflected in the median completion rate value of 12.5% (Jordan, 2015). Koller, et. al. (2013) propose that retention metrics are only useful through the lens of the learner’s goals. As an example, a student may gain substantial value from watching videos while never completing any of the assessments (Koller, Ng, Do, & Chen, 2013). To expand upon these ideas, Eriksson, et. al. researched student motivation for stopping out in MOOCs by conducting 34 interviews with students from two different MOOCs. This study found that motivation was a key factor for student stopout/completion. The only other factor that came close to the mentions of motivation was lack of time as a reason for stopout (Eriksson, Adawi, & Stöhr, 2017).

While some qualitative studies such as Eriksson, et. al. exist, such studies are rare. Qualitative research on MOOCs has often involved examining data from discussion forum communications (e.g. Eynon, Hjorth, Yasseri, & Gillani, 2016). One study involved autoethnography data from three researchers who each enrolled in different MOOCs and wrote detailed notes of their experiences (Park, Jung, & Reeves, 2015). Veletsiansos, et. al. (2016) conducted a landmark study involving 92 interviews with MOOC students in four MOOCs. This study focused on self-regulated learning and distance learning persistence through understanding students’ contexts and goals. Veletsiansos, et. al. (2016) emphasized the importance of qualitative MOOC research as a way to create a larger perspective of student experience beyond viewing students as numbers in a dataset (Veletsiansos, Reich, & Pasquini, 2016). Overall, qualitative research is needed to add nuance to the current quantitative findings as was done by Eriksson, et. al. As such, this paper will examine learner motivation in MOOCs and offline behaviours related to the lab kit to add nuance to findings from quantitative MOOC research. As Veletsiansos, et. al. (2016) stated, “students exist and participate in MOOCs in ways that leave no record in tracking log.”

Data Collection

Over 24,000 students participated in this MOOC. A randomized control trial (RCT) was used to gather data from over 5,000 self-selected students. The treatment group consisted of approximately 180 students who received an at-home lab kit corresponding to the DIY lab example videos. Students not in the treatment group had the option to purchase the at-home lab kit, though only a few did. Both the control and treatment groups were given pre- and post-surveys, and their clickstream data were collected throughout the course. Students were recruited for interviews from both the treatment and control groups and based on strata identified through prior work (Atiq et al., 2015). Students were placed into strata based on their online participation measured through pageviews (high and low categories were determined based on the average pageviews in the course) and performance measured through final grade (passed high, passed low, failed, and stopped out) in the course. This
process created a total of eight strata. This stratification allowed researchers to understand how these two elements related to their offline behaviours and motivations. Students interviewed ranged from those who passed with high grades and high page views to those who stopped out with low pageviews. Interviewees spanned 5 continents and totalled 55 participants. As shown in table 1, these interviewees spanned all strata. Thus, saturation has been achieved through the large number of interviews completed as well as the diversity of students represented. Semi-structured interviews were completed via skype and contained questions probing student expectations, experiences in the course, and experiences with the lab kit. Interviews were audio recorded and transcribed verbatim. Participants were randomly assigned pseudonyms to protect their identities.

<table>
<thead>
<tr>
<th>Treatment Group</th>
<th>Control Group</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>N</strong></td>
<td>12</td>
</tr>
<tr>
<td><strong>Strata Represented</strong></td>
<td>5</td>
</tr>
<tr>
<td><strong>Researchers Coding</strong></td>
<td>2</td>
</tr>
<tr>
<td><strong>Theme Generation</strong></td>
<td>Initial themes were formed separately, then researchers came together to refine these themes and develop the final themes.</td>
</tr>
</tbody>
</table>

**Thematic Analysis**

Thematic analysis was used to analyse the 55 interviews. The process of doing thematic analysis was conducted in two rounds, coding for the treatment group (12 interviews) and then coding for the control group (43 interviews). These rounds consisted of the same process. First, researchers familiarized themselves with the data. Researchers then generated initial codes. These initial codes were categorized into themes. These themes were refined and reorganized in alignment with the initial research questions. Finally, themes were condensed and defined. For the treatment group, both researchers completed initial coding separately. The researchers worked together to condense and align these codes to develop themes. Final codes were related to one another through larger groups described in a thematic map and via a thematic report. This process was adapted from the thematic analysis proposed by Braun & Clarke (2006). This work-in-progress paper focuses on selected codes found through a larger thematic analysis that describe students' motivations and their offline behaviours, as these two areas can only be understood through qualitative insights.

**Findings and Discussion**

**Student Motivation**

Since this course offers no institutional credit, the usefulness of the course was defined by each student and related directly to each student's goals and needs. While these needs were diverse, most could fit into one of two groups: teachers using this course as a guide or resource for teaching neuroscience and professionals or students using the course to fill in details missing from current or previous coursework.
Some, such as Bob, fit into both groups as a teacher who used this course to refresh his knowledge and then applied that knowledge to his classroom.

“I thought interesting, interesting visuals there. Professor was nice. He was knowledgeable and I guess I used them both and just refresher for my own knowledge and …I used even some material in classes I teach.” – Bob

Other teachers found the materials useful for their classes. This usefulness was particularly true for the treatment group who received the lab kit, who often used it as a supplement to otherwise strictly theoretical classes. Alex tells how he demonstrated the kit on his students.

“I demonstrated the instrument in my class, in the lecture class and I, and I summoned my students and pop leads on electrode, electrode sub leads on my students and let them see how it was spiking and let them measure and show them that these are the action, these are what you see and these are the peaks so in magnitude and, and these are the times, these are timescales highs on the skills. We can measure how much is the, ah, duration, degree in the spikes et cetera, so they also enjoyed.” – Alex

The group using this course to supplement or fill in missing knowledge consisted of three smaller groups. These three groups were professionals using this knowledge for projects, students using this course for studying or supplementing their classes, and a group using this course as a place to initially explore these topics. For this first sub-group, professionals often used this course to supplement their understanding of specific aspects of this content area, including research. For some like Jasmine, this course was also used to familiarize themselves with the nomenclature used in the field of neuroscience.

“I am doing research on CTE and have a high interest on the topic” - Stephen

“I had just, uh, started a research project studying multiple sclerosis and I wanted a little bit more background because I do know the pathology part, but I wanted to know the theoretical neuroscience of, you know, just the general central nervous system. I thought that might give me a little bit more of a command over the nomenclature used, certain assays that are used, when I'm reading, you know, journal articles and stuff like that. So I, that's basically why I signed up to that course, to gain more information, more basic information that wouldn't make me sound stupid when I'm talking about the diseases that I'm studying.” – Jasmine

Students used this course to supplement the learning they were currently doing in formal educational settings and to refresh themselves on previously learned topics. For Aiden, this course was mostly a refresher, while for Matthew, this course was used as a study group in preparation for medical school.

“The clinical part and basic anatomy is [sic] all covered in my university courses. Might I say a bit more detailed than this course but again I was anticipating this difference when I learned about the coordinator's background… (I registered) mostly to refresh and learn my basics.” – Aiden
“I want to pursue a career in medicine, and I'm applying to medical school this year in May. I believe this program and the other programs online are a great source to learn more, especially before I start any career. During my undergrad, I was with some of my friends. We took the class together. When we took the class together, we motivated each other and made sure to get together to do the class together. That helped a lot.” - Matthew

The final subgroup used this course as a safe place to explore these subjects. This exploration was often more preliminary than the other two subgroups. This could range from considering a science degree to considering a new research pathway.

“I'm doing linguistics but I want to turn more into psycholinguistics or neurolinguistics. I decided to take this course to get an idea what neuroscience is.” – Abigail

“I had been toying with the idea of going back to school and, maybe, doing something about my passing interest a little more formally. I don't have a background in hard science. I went the liberal arts way during undergrad, and, so, I thought it would be a great way for me to get a better handle on the basics so that I can know what people are talking about should something formal happen.” - Addison

Students’ distinct areas of interest in this course varied from psycholinguistics to multiple sclerosis to teaching, and their motivations varied as widely. Yet, the broader motivations that were identified in the thematic analysis could easily be divided into groups and subgroups. These groups may engage differently with the course to meet their needs. Some students expressed their unwillingness to engage in the discussion forum due to the lack of more extensive knowledge. Some expressed that the topics in the discussion forum went too far away from the fundamentals. While more research is needed, this tension may be the result of the subgroup that was focused on the fundamentals encountering the subgroup of professionals. While the professional's subgroup may benefit from information connecting the fundamentals to more advanced information, the subgroup of explorers may feel overwhelmed venturing away from the fundamentals. Additional connections to others within their subgroup may create study opportunities like those experienced by Matthew offline through his student study group during his undergraduate studies.

Lab kit usage

Lab kit usage often triggered or supplemented online behaviour. For some students, their studying and lab kit use caused them to consult the online forum to discuss results, find clarification, or interpret experimental results.

“Yes, uh, we used the forum for the experiments because sometimes we had difficulties in interpreting the results of the experiment and we ask on the forum and every time we had the answer very, very quickly. Even in the, in the night and the weekends. I think it's very important because sometimes we really have to, to talk with the other students, or even the teachers. I think it's necessary.” – Kurisu

Kurisu was the daughter of a mother-daughter pair that worked together. After attempting to figure out an assignment themselves, they often asked for help on the forum. However other students did not feel heard when asking for help, so some turned to offline resources to assist their learning.

Many students engaged in amplifying behaviours where they used the lab kit to teach others what they had been learning outside of the online class assignments or curriculum. As shown in the motivations section, many teachers used the lab kit to instruct their classes on neuroscience. Beyond this interaction, students demonstrated this kit to their colleagues, friends, and children.

“I used it primarily in the experience of the (stimulation) excitement of the nerve. I even did the demonstration in front of my children who were delighted.” - Max
Students expressed that this kit gave them an easy way to explain what they were learning to others and create excitement around neuroscience. This additional behaviour of interacting with others who were not in the MOOC enhanced their experience with the lab kit by allowing the students to co-construct their neuroscience knowledge.

The most unexpected use of offline materials was student improvisation in use and specimen type for the at-home lab experiments. Alex, whose quote is given in the motivation section, conducted the experiment first on himself and then on his students. Like several other students, he expressed distaste in 'animal experimentation'. As a reminder, the experiments with the kit are built for invertebrates such as earthworms and cockroaches. His self-experimentation led him to understand one of the subjects explained in class.

“I put a stem muscle into use, I contracted the muscle and so the activity, ENG activity in the SpikerBox in the Backyard Brains Software and so on audacity and that was, that came as usual. When I was about to untie and link the electrodes pin, I suddenly found that although I was not using the muscle, although I was not contracting the muscle voluntarily or it isn’t any load, the ENG went for other sounds in the Backyard Brain’s Software but coming. So, I was a little bit perplexed and then ah, I realized that I took a big breath, I inhaled, I, I took a big breath and ah, I inhaled like this (breathes). So, ah, that was a deep inspiration and then accessory muscles were holding. Some although we read it in the textbook but we saw it first-hand … I saw it first-hand on the Backyard Brain Software and that ah, this muscles did not usually act in when we take normal respiration, but when we take a deep breath and that’s why these accessory muscles, …kind of serendipity.” - Alex

Several students commented on obtaining specimens. Some students obtained different insects from the local pet store, yet another bought a full pack of the recommended cockroaches and worms. A student reported not using the lab kit at all due to having a phobia of cockroaches, while another was not scared to use the spiker box on himself directly and was confident about the safety and science behind it without this information being provided in the online class content. Ana tried different test subjects after she was unable to get cockroaches.

“It was a whole fun experience for me. First of all, in my country, it's impossible to get a cockroach that was recommended for the assignment. So I had to improvise a little bit. I also had some other species to play with and, and I, I even tried to measure spikes from my dog's ear which I didn’t succeed in doing. But, you know, I really had a lot of fun and it wasn't limited to the time.” – Ana

The reaction of so many students denotes a potential issue using insects in relation to at-home experiments. However, these quotes also speak to the flexibility of students and the impact of this lab kit on their understanding. While some offline behaviors were expected, students did have unique offline interactions through interaction between online and offline behaviours and amplifying behaviours. These behaviors added additional collaboration and construction of knowledge, which has been associated with student success (Menekse, 2012).

Implications

The insights from the analysis offer implications into potential areas of follow-up work for both design change and future research within MOOCs.

MOOC designers could match students with others from similar motivation groups. This concept would resemble online communities of practice. Community of practices are groups common interests and concerns who have the goal of improving their knowledge in a specific area (Wenger, 2002). Several students expressed a mismatch between the types of discussions available on the forum and their own goals. Thus, students may feel more able or willing to participate in a discussion forum of people who share similar goals. This simple
change could be expanded to the whole course. Teachers could be put into a community of practice that contains additional material on how to teach this information or how to adapt the course information for their classroom. Professionals could be put into a version that allows for more networking and makes additional connections between the fundamentals and other materials. Even without making specific tracks for each motivation type, designers could still add extra materials for teaching or extra materials for connections as supplements to the larger course. Future research should evaluate the impact of adding these materials on student motivation. Research should also investigate whether separating student by motivation type increases forum use or motivation among students.

The lab kit created new opportunities to collaborate and share the neuroscience and electrical engineering principles students were learning in class. Student lab kit use expanded far beyond expected use by the students as the use allowed students to amplify their learning by sharing with others and collaborating with others on the discussion forum. This effect could be extended by encouraging or even requiring students to post or discuss their results. This student discussion forum data could allow for further analysis. Research could help determine how best to expand students’ understanding of STEM principles by mixing the offline (lab kit) and online (forum) experiences.

More fundamentally, future research would benefit from a richer understanding of students’ complex motivations, and their life offline more broadly. Like the MOOC examined in this paper, many MOOCs offer no institutional credit meaning that motivations to take these courses are often intrinsic coming directly from the student’s goals and needs. Beyond the need to understand motivation, online students are flesh and blood as emphasized Veletsianos, et. al. (2016) who have lives beyond their clickstream data.

Conclusion

Overall, motivational profiles identified inductively by student and offline behaviours give a nuanced picture of student experience in the course. While students enter and exit the course for a variety of reasons, their general motivations give insight into the needs of various student groups and how they hope to use the course. This insight can be used by course designers to differentiate experiences for each of these groups or to offer resources to help specific groups within the course. No matter what group, students used the lab kit in several unexpected ways leading to amplifying or collaboration experiences. Designers could play on this natural behaviour to extend student learning. The MOOC environment offers thousands of students per class with each student possessing distinct motivations and experiences. Yet even in such a large course, this research has shown that student-centred activities and environments are still possible.

References


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Individual versus collaborative study behaviours while using an automatic answer-checking feature

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Abstract: In online learning environments, automatic answer-checking features provide students with immediate feedback, allowing them to regulate their problem-solving strategies. Understanding how students integrate feedback in their study strategies is essential to better assess the role of technology-mediated tools in online learning. In this study, we analysed video-taped think-alouds of students solving problems in order to compare how they integrate feedback in their study strategies when they work individually versus in groups. We performed non-parametric comparisons of time proportions spent on different problem-solving activities. The results show that problem solving and information-seeking behaviours differ significantly when students use the Checkable Answer Feature (CAF) in groups versus individually. The observed differences in study behaviours suggest that future designs of automatic feedback systems such as the CAF should take into consideration the collaborative dimension in online learning.

Introduction
Internet-based technologies are becoming pervasive in today's higher education and constitute an integral part of blended learning. Also called hybrid learning, blended learning can be defined as the integration of face-to-face learning experiences and online learning experiences (Garrison & Kanuka, 2004; Murphy, Means, & Marianne, 2014; Zhao & Breslow, 2013). The online component of blended courses provides students with a resource-rich environment, allowing them to enact a variety of study behaviours (Breslow et al., 2013). For instance, collaborative study behaviours were found to have a positive impact on course's retention (Prince, 2004). In fact, collaborative work was found to promote the feeling of connectedness, which is critical for learners (Borras-Gene, Ez, & Fidalgo-Blanco, 2016). However, research shows that different groups may benefit differently from resources available in blended courses. In other words, not all groups have equal access to resources that have been shown to benefit students. For example, Bayeck (2016) found that when group work is included in a MOOC, women tend to participate more. Contrarily, Liu (2016) suggested that due to linguistic and cultural barriers, international students may be reluctant to interact with their peers, thus hindering any collaborative work. In addition, Xu & Jaggars (2013) found that “at-risk” students struggled more than others in adapting to online learning resources. Therefore, in order to better assess the role of technology-mediated tools in blended-learning courses, we need to understand how students are really using these tools and if such use differs when students work in group or individually.
**Context**

PHYS101 is an introductory course on classical mechanics required for all students at an elite private university in the USA. This course is a highly-structured, blended course, with three in-person class meetings per week and an online site based off a widely-used MOOC platform. Among the online resources available to students is a rudimentary feedback system, the Checkable Answer Feature (CAF). The CAF returns a green tick mark when the entered answer is correct, and a red X if it is wrong. In solving their homework problems, students used the CAF feature to check if their answers were correct or not and to officially submit some of the homework problems. In this paper, we compare students’ study behaviours during homework problem sessions in two scenarios: in groups and individually.

**Literature review**

**Feedback**

Hattie and Timperley (2007) define feedback as “the information provided by an agent (e.g., teacher, peer, book, parent, self, experience) regarding aspects of one’s performance or understanding” (p. ?). Feedback plays an important role in closing the gap between current understanding and the desired learning goal (Chen, Breslow, & DeBoer, 2018). Online learning platforms provide students with the possibility of getting automatic instant feedback through programmed systems embedded in the platform. Previous studies found that immediate feedback systems, like the feature studied in this paper, gave students the opportunity to identify learning needs and come up with strategies to address them (Crisp & Ward, 2008; Gijbels, Dochy, Van den Bossche, & Segers, 2005; Sorensen & Takle, 2005; van der Pol, van den Berg, Admiraal, & Simons, 2008).

**Group interactivity**

As online courses become more popular, instructors are raising important questions regarding the quality of these courses and programs (Muirhead, 2019). Among those questions, interactivity between students is often brought up as a major concern for educators (McNabb, 1994; Sherry, 1996). In fact, many advocates of online learning have observed that group learning has focused mainly on the content and self-study lessons instead of interaction (Boshier, Moulton, Mohapi, & Qayyum, 1997; Hiltz, 1997; Hassenplug & Harnish, 1998). As defined by Moallem (2003), two types of interactivity in online learning can be identified: a) cognitive or individual interaction with the content and b) social or interpersonal interaction. While both are complementary and equally important, social constructivists have argued that the human interactivity dimension is the cornerstone of learning (Chaiklin, 2003; Vygotskii & Kozulin, 1986; Gilbert, 1998). The social constructivist notion of interactivity emphasizes collaborative and cooperative learning environments that foster active dialogue (Moore, 1989; Saba & Shearer, 1994).

**Problem solving**

Many scholars have investigated how individuals and groups solve problems. Since the early work of Polya (1957), Wertheimer (1959), and Bajnbridge (1973), different models have been developed in order to explain how individuals solve problems. Bransford and Stein (1993) proposed the IDEAL model which identifies five primary components of problem solving: identify problems and opportunities; define goals; explore possible strategies; anticipate outcomes and act; and look back and learn. Multiple other models of problem solving have utilized a scientific method to represent how ideas, methods and products develop in a group setting (Hare, 1992). While the IDEAL model was developed specifically for individual problem solving activities, it can also be applied in the context of groups. Within the IDEAL framework, there are different phases of development in which groups define a situation, acquire resources, develop the roles of individual members, coordinate tasks, and finally come to a common agreement. As described by Lou and Kim MacGregor (2004), when
solving a problem in groups, individuals act in isolation first and then come together to share or combine their products with the rest of the group.

**Research questions**

The purpose of our study is to answer the following research questions:

**RQ:** Do students' study strategies differ when they interact with the Checkable Answer Feature (CAF) individually versus in groups? If so, what types of study behaviours differ between students using feedback individually or in groups?

Understanding how students incorporate the CAF into their group learning process is essential not only to identify future improvements of the CAF but also to assess if more beneficial activities are implemented in individual or in group sessions.

**Methodology**

**Sampling**

We observed a sample of students doing homework problems using the online platform. Students were recruited for observations via a stratified random sample based on current performance in the class (approximately two-thirds of the way through the semester). Students were asked to come in to a lab setting and solve problems as they would “typically” for a homework session, whether they usually worked alone or with other students. If they “typically” worked with other students, they were invited to bring their peers along. Students completed think-aloud protocols as they finished one or more online homework problems. These problems were due approximately four days after the observation sessions, so students were completing homework problems that they were required to do for their grade in the class.

**Observation Sessions**

Observations typically took 45 to 60 minutes. In total, we conducted 17 observation sessions, and in 5 of them the students solved problems in collaboration with one or more friends/classmates. The interactions were audio and video recorded using two cameras: one pointing to the student’s screen and one pointing to his/her face. Such a setting allowed us to capture the student’s study behaviours and reactions while triangulating them with their progression in solving the homework problems. Before each observation session, a member of the research team explained to the participants the think-aloud protocol that they were supposed to follow. That protocol asked the students to verbalize the different steps that they were taking when solving the problem (Someren, Barnard, & Sandberg, 1994). For example, a student who used Google would say, “I am searching in Google for the definition of linear momentum”. As part of the think-aloud protocol, the researcher, who was present during the entire session, prompted the students with follow-up questions at different stages to continually elucidate their thought process, such as “Can you tell me what you’re thinking?” or “How confident are you that you got the answer correct?”.

**Data Analysis**

The recorded videos of the homework sessions (individual and group) were coded using a structured codebook implemented via the software StudioCode. The cameras’ configuration allowed us to visualize simultaneously the students’ behaviours, students' affect, and their progression in solving the homework problem. From initial review of the observation sessions and iterative discussions in the research team, an initial coding scheme emerged containing three types of study behaviours: problem solving, resource choice, and affect. In concordance with the study’s research questions, these three types of study behaviours were refined and led to the emergence of 16 study behaviours. Table 1 provides a description of each study behaviour. For example, a statement such as “This is like the one we did in class, we need to find acceleration here” was coded as a “problem identification” study behaviour.
because the student had recognized the genre of the problem assigned. This fits under the larger heading of “problem solving”. Also, a statement such as “Yes! it’s the correct answer” would be coded under as an “affect” under excitement.

Table 1: Description of study behaviours

<table>
<thead>
<tr>
<th>Type of study behaviour</th>
<th>Study behaviour</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem solving</td>
<td>Conceptual question</td>
<td>Asking questions about a subject or/and asking for information about a topic</td>
</tr>
<tr>
<td></td>
<td>Method question</td>
<td>Asking how to do something</td>
</tr>
<tr>
<td></td>
<td>Method explanation</td>
<td>Explaining how to do something</td>
</tr>
<tr>
<td></td>
<td>Discussing potential solutions</td>
<td>Talking about different solutions that might work for a given problem</td>
</tr>
<tr>
<td></td>
<td>Problem ID</td>
<td>Identifying a problem</td>
</tr>
<tr>
<td></td>
<td>Implementation</td>
<td>Implementing the solution</td>
</tr>
<tr>
<td></td>
<td>Post-evaluation</td>
<td>Evaluating effectiveness of a solution or the technique used</td>
</tr>
<tr>
<td></td>
<td>Arbitrary guessing</td>
<td>Making guesses about potential solutions, information, or hypothesizing</td>
</tr>
<tr>
<td>Resource choice</td>
<td>Evaluating Resource</td>
<td>Judging a resource, offering opinion about it</td>
</tr>
<tr>
<td></td>
<td>Google search</td>
<td>Using google</td>
</tr>
<tr>
<td></td>
<td>Use of online textbook</td>
<td>Using the online textbook that was part of the course resources</td>
</tr>
<tr>
<td>Affect</td>
<td>Frustration</td>
<td>Anger due to struggling with problem</td>
</tr>
<tr>
<td></td>
<td>Thoughtfulness</td>
<td>Thinking about a problem</td>
</tr>
<tr>
<td></td>
<td>Confusion</td>
<td>Being confused by the problem or how to solve it</td>
</tr>
<tr>
<td></td>
<td>Excitement</td>
<td>Happy emotion</td>
</tr>
<tr>
<td></td>
<td>Confusing</td>
<td>Students finding a resource to be confusing to interact with</td>
</tr>
</tbody>
</table>

For each case (i.e., individual and in-group sessions), the video analysis led to a time quantification of the above study behaviours for each student or group. The resulting time durations of each of the study behaviours were then normalized relative to the homework session’s length. The normalized time durations of each study behaviour were averaged over the total observations in each case. Finally, we performed a Mann-Whitney test on the average time of each study behaviour to test for any significant difference between the two cases. Due to skewness of both data samples and their small sizes (< 20), we opted for a non-parametric test (a two-sided Mann-Whitney test). The only assumptions for carrying out a Mann-Whitney test are that the two groups must be independent and that the dependent variable is ordinal or numeric (continuous). In our case, both assumptions are satisfied, since the students from both groups were different and the dependent variable is a normalized time duration. The null hypothesis is:

$$H_0: \text{The average times spent on study behaviour } i \text{ by students working in group or individually are the same}$$
We should note here that since we are not testing a universal null hypothesis, there is no need to perform any correction such as the Bonferonni correction (Armstrong, 2014).

Table 2: Mann-Whitney test for individual vs. group study behaviours time percentage

<table>
<thead>
<tr>
<th>Study behaviours</th>
<th>Normalized session length (%) (Individual)</th>
<th>Normalized session length (%) (Group)</th>
<th>U-statistic</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem identification</td>
<td>5.18</td>
<td>4.23</td>
<td>22</td>
<td>0.491</td>
</tr>
<tr>
<td>Post Evaluation</td>
<td>2.61</td>
<td>1.94</td>
<td>28</td>
<td>0.948</td>
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<tr>
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<td>29</td>
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</tr>
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</table>

*p ≤ 0.05    **p≤0.01   ***p≤0.001

Results

Individual session

Figure 1 shows the comparison of the time share (normalized session length) for each of the study behaviours in both individual and in-group sessions. When working individually on their homework problems, students spend 68% of the overall session’s time solving the problem, 19% using resources, and 11% expressing emotions.

Group session

In the case of students working in groups, we observe a similar distribution to the individual case but with a higher time portion spent using resources. In fact, when working in groups, students spend 67.11% of the overall session’s time solving the problem, 23.80% using resources, and 10% expressing emotions. Similar to the case of individual students, we find that 50% of the overall session is split between discussing potential solutions (23.28%), using Google (20.22%), or implementing those solutions (17.52%).

In both samples, resorting to Google appears to be the most commonly used resource. As shown in the graph for individual students, using the search engine took up 15.79% of the
homework session’s total length compared to barely 1.77% for using the online textbook that was created specifically for this course. For students working in groups, using Google constituted almost 20.22% of the time in a homework session, while the time spent using online textbook remained as low as 2.16%.

Whether using the checkable answer feature (CAF) in groups or individually, students’ most noticeable emotion was thoughtfulness (around 8.21% for individual students and 5.28% for groups).

Overall, whether working in groups or individually, students spend most of their time working on solving the homework problem.

**Significantly different study behaviours**

**RQ:** Do students’ study strategies differ when they interact with the Checkable Answer Feature (CAF) individually versus in groups? If so, what types of study behaviours differ between students using feedback individually or in groups?

Table 2 above summarizes the results of the U-test where 7 study behaviours were found to differ significantly between students working individually versus in group. With the exception of using Google, the remaining 6 study behaviours that were found to be significantly different are problem solving behaviours.

![Figure 1: Study behaviours’ time percentage for individual and group cases](image-url)
For the problem-solving behaviours, Figure 2 shows that the time spent asking and explaining conceptual questions related to the homework differs significantly between students working individually and in groups. For instance, when working in groups, students spend 4.64% of the session’s time asking conceptual questions and 10.45% giving a conceptual explanation. For instance, one student would ask, “What is the gravitational constant?” to which another student would give an answer explaining that concept. On the other hand, individual students spent almost half of what students in groups spent in asking conceptual questions (2.23%) and less than two-thirds of the time the group used in giving conceptual explanations (6.26%). Furthermore, the U-test’s results show that the time spent implementing the solutions of the homework problem is significantly different with individual students spending more time (23.4%) than students in groups (17.52%).

Using Google was the only resource choice behaviour that was found to differ significantly between the two cases. In fact, while students working in groups spent 20.22% of the overall homework session using the search engine, students working individually spent only 15.79% using that same resource.

Discussion and implications

The results of this study show that some study behaviours differ significantly when students who have a simple feedback system available to them work in groups versus individually. Overall, we can conclude that when students work in groups with the checkable answer feature (CAF) as part of the online resources they can access, the group spends a higher proportion of time on problem solving behaviours. Specifically, as shown in Figure 2, students working in groups tend to spend more time asking conceptual questions, providing conceptual explanations to these questions, and discussing their potential solutions. On the other hand, when it comes to actually implementing the solution, students were found to spend more time when they work individually versus when they work in groups. Rushing toward implementation is actually a characteristic trait of a novice while spending more time in planning is characteristic of experts (Smith & Leong, 1998). Furthermore, the higher proportion of time spent in discussing, asking questions and explaining concepts illustrates the social constructivist notion of interactivity in online learning (Moore, 1989; Saba & Shearer, 1994; Harskamp & Ding, 2006). This finding does correspond with the sociocognitive literature that states that learning is a social activity and that individuals learn...
more from their interactions with others than from reading materials alone (Levin, 1983; Sharan, 1980).

This study also shows that when groups of students have the CAF, they tend to spend more time using the online search engine (Google). While this finding might appear counterintuitive, it actually points to what Lou and Kim MacGregor (2004) described as a specific pattern of collaborative problem solving. Their work showed that when solving a problem in groups, individuals act in isolation first and then come together to share or combine their products with the rest of the group. Our work confirms that solving problems in groups involves both an individual component (e.g., searching Google) and a collaborative one (e.g., discussing potential solutions). Given the promises of blended learning for expanding the array of study tools available to learners, it is important to understand how students actually make use of tools like automated answer checkers especially when they integrate such tools in their collaborative learning. A better understanding of the use to tools such as the CAF can help improve further designs in order to account for observed differences between individual and group use. Future work will investigate the different temporal sequences of study behaviours and what are the study strategies that the students find the most helpful.

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Busy Times, Productive Students: Cutoff Points Marking Time in University Engineering Culture

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Abstract: Understanding how engineering students cope with increasing academic and professional-skill-building demands on their time has important employment implications. Through individual and group interviews, we focus on the ways in which students navigate time in relation to their academic, extracurricular, and personal activities. Time markers of various types emerge as a key theme as students are exposed to unfamiliar academic content and an increase in course workload. Students believe extracurricular activities enhance their appeal to prospective employers. Students surviving an intense and rigorous program offer insight into the organizational culture of an engineering school and student preparation for the job market.

Every year, millions of U.S. university students are indoctrinated into an oftentimes intense culture of learning as academic demands rise. Simultaneously, students are typically transitioning into adulthood, acquiring daily life skills in a setting frequently at a distance from sources of parental support (Astin 1993). Time, in all of its dimensions, plays a critical role in shaping student experiences, perspectives, and performance (Burke et al. 2017; Liao et al. 2013). A focus on time in relation to student activity enables us to explain how a university organizational culture functions and has the potential to leave an indelible mark on student preparation for the future workforce.

Understanding Time

Definitions and Categorizations

The concept of time defies commonality in definition and description. For Durkheim, time is “the rhythm of a life…in which all participate” (1965: 489-90). Weber’s understanding of time is largely evaluative: “Waste of time is…the deadliest of sins” (Weber 1958: 157). Hall (1983: 3) considers time “as a language, as a primary organizer for all activities …” among many other descriptors. Cheng (2017: 145) asserts that time is “a type of social fact that is defined by social institutions and social practices.”

A common focus in temporal research involves capturing study-participant perspectives and other elements of reckoning time. Time associated with both work and social settings has been categorized as “scheduled,” “personal,” “thought,” “compressed,” “wasted,” “project,” and “timeless” (Liao et al. 2013; Ylijoki and Mantyla 2003; Zucchermaglio and Talamo 2000).
Another way of understanding time involves identifying attributes such as regularity (i.e., routine) and density (i.e., constancy) (Snyder 2013). Kluckhohn and Strodtbeck’s (1961) work, analyzing perspectives on the past, present, and future in five cultural communities, has served as the foundation for understanding cross-cultural differences from a values perspective (Hofstede 1991). Hall (1983) contrasted cultures with distinctive time orientations. Monochronic-time cultures conceptualize time as sequential: tasks are the focus of attention, handled one at a time, and typically coordinated within schedules. Monochronic time tends to be found in cultures where a high value is placed on getting the work done (e.g., U.S., northern Europe). Polychronic-time cultures are synchronically-oriented: a number of activities occur in parallel; plans may change since social relationships are prioritized over tasks (e.g., the Orient, Latin cultures). Considering the various meanings study participants ascribe to time is a first step in understanding how temporal elements are interwoven in a particular cultural context.

**Busyness in Time and Culture**

One dimension of time has received significant attention across disciplines and in selected Western nations including the U.S. It is referenced as “busyness,” “harriedness,” “acceleration,” “compression,” “intensification of time use,” and “time squeeze,” among others. In general, these terms and phrases suggest engagement in activity on a relatively continuous basis and at a fast pace (Graesch 2009; Levine 2005; Starkey 1988). The busyness literature is tied directly to culture, defined by Ferraro and Briody (2017) as “Everything that people have, think, and do as members of their society.” Indeed, time and culture are virtually inseparable (Hall 1983); as culture evolves, conceptions of time change (Starkey 1988) — including busyness. A definition from the turn of the 15th century emphasizes being “constantly occupied with many things” (Snyder 2013: 258), suggesting an array of different activities. By the mid 19th century, the term busy referenced the continuous movement of squirrels, some of which seemed decidedly less essential than others (Greenfeld 2005). Busyness as portrayed in U.S. advertisements at the turn of the 20th century implied “distractibility and lack of focus” (O’Malley 2005: 377).

Busyness became linked with the intensity and pace of work through Taylorism, particularly “the ‘one best way’ of doing work” (Starkey 1988: 101). After World War II, the concept of work became increasingly dominant such that leisure time was largely belittled (Levine 2005). That leisure pattern reversed, introducing a paradox: as leisure time has increased, so too has busyness (Gershuny 2005). Busyness is tied to everyday activities (Darrah 2007; Darrah, Freeman & English-Lueck 2007), with some arguing it stems from a lack of prioritization of activities (Greenfeld 2005), and others asserting it has become culturally expected, and viewed as a crucial personal value, marker of identity, and even a social norm associated particularly with prosperous or privileged groups (Bellezza, Paharia & Keinan 2017; Gershuny 2005, Graesch 2009). In our earlier work, we simply found that the term “busy” was associated with being “fully-scheduled and fast-paced” (Briody et al. 2019).

**Time Management and Peer Collaboration**

The use of time intersects with students’ lives at multiple levels. For instance, students new to university life and culture have to become conversant with the requirements, content, and strategies to complete their programs successfully. Their days are structured by various activities including courses: “scheduled time...gives people on a modern university campus their rhythm of life” (Liao et al. 2013: 148). Organizing and planning daily and weekly activities, or time management, becomes an essential skill in response to “institutionally imposed time structures” (Burke et al. 2017) such as a course schedule or tutoring hours. Time management has helped students navigate academic and personal challenges and reduce stress (Misra and McKean 2000).

Synchronizing learning opportunities through collaborative group work can help address academic challenges (Briody et al. 2018). Students introduce and discuss ideas and typically
arrive at a shared understanding of a particular engineering concept or question. Group work and collaborative learning are contingent on aligning schedules to avoid “disorganized rhythms” (Southerton and Tomlinson 2005: 232). Examining how students relate to the temporal conditions associated with their university department or school’s organizational culture enables us to make sense of their preparation for the workplace. Both the university and the workplace are complex environments requiring prioritization and time management.

Our focus is on the organizational culture of the Engineering School (ES), with particular attention to its temporal elements. We explore the connections between aspects of time relevant to ES students, and their perceptions of their potential future. Key questions include:

1) How do students describe their engineering program? Which dimensions of time are salient for them as they pursue their degree?
2) How do students adapt to the rigorous demands of their engineering program?

Methodology

Our interdisciplinary team from anthropology, sociology, mechanical engineering, and industrial engineering used an anthropological approach. We employed ethnographic methods – a mix of individual and group interviews, documentary/digital sources, and survey data. IRB approval was secured, and all participants consented.

Data Collection

Data gathering targeted ES students, primarily through interviews (See Table 1). We used nominated-driven sampling to identify interviewees who were willing to share their ES experiences with us (LeCompte and Schensul 2010). This kind of sampling is common in anthropological research because it relies on developing rapport and building trust with interviewees. Our sample was self-nominated based on professors’ networks and “open-calls” in selected ES classes where we described the study and solicited volunteers.

We conducted 10 of the 12 individual interviews at the start of our project in 2015, focusing largely on 4th year students (4YS) who had the longest association with the ES. We conducted 21 of the 23 group interviews in 2016-17; they were designed to enhance our understanding of the student experience at the outset and midpoint of the major by involving third year (3YS) and second year (2YS) students. The interview questions target viewpoints on ES organizational culture generally, and student daily life specifically. We also sought student perspectives on success during their university experience.

<table>
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<th></th>
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<th>2nd Year Students (2YS)</th>
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<td>69</td>
<td>69</td>
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Table 1: Interview sample by number of bachelor students and time duration

Data collection included explorations of the university and ES websites. We sought information on ES organizational culture including ES values, program offerings, and highlighted benefits. We also examined ES brochures offering detail on program requirements and courses, study abroad, work opportunities, and extracurricular activities.
Finally, we conducted surveys each semester between 2015-2017 by sending emails to ES students. Among the 629 valid responses, 31% (N=194) responded to the relevant survey questions which focused primarily on work-life balance.

Data Analysis

We used content analysis to identify themes and patterns in the interview data (Bernard 2011). As we read the transcripts, it became clear that various elements of time were a dominant theme (e.g., complaints about insufficient time for homework and studying). Three members of our research team completed a preliminary coding of a sample of interviews and settled on a set of codes for the larger interview data set. Our process involved continual or constant comparison of the codes and the segments of text associated with them.

Next, we compared key themes from the interviews to themes from the survey results and documentary/digital data. Selected survey analyses and data from documentary sources helped broaden our understanding of the temporal features of ES organizational culture. We focused on the extent of similarities and differences across the entire data set to refine our analysis and its interpretation. Our findings were validated through informal conversations with ES students who did not participate in the study, as well as with selected faculty.

Background

The setting for this study is a large, public, midwestern university in the U.S. with over 30,000 students. As a R1 doctoral institution, a designation by the Carnegie Classification of Institutions of Higher Education, this university is credited with extensive research activity. The 80 ES faculty members primarily focus on research. Faculty are expected to teach at least one course per semester to the 1,400 ES bachelor students. Professors work together to agree on and teach course content in engineering fundamentals to new majors.

Admission to the ES major is highly competitive, requiring 128 course credits for graduation with a Bachelor of Science degree. The ES website, admissions' brochures, and other documents laud its educational and work-related opportunities. ES students acquire analytical, problem-solving, and “hands-on” skills through their courses. Students gain “global perspectives” by working or studying abroad; internships and coops help connect classroom learning to engineering practice.

Results

The ES Experience through the Lens of Time

Student Descriptions. ES majors allude to various aspects of time (in bold font) including their schedule and its pace:

- “I do homework and study pretty much the entire day with the exception of when I go to class, of course, and eat dinner. Sometimes I’m doing homework until 8:00 p.m. and starting at waking up at like 9:00 a.m.” (2YS).
- “Just as far as time goes with ES, it almost seems like the entire semester we’re running 100 miles per hour” (3YS).

Their statements make clear what they are doing – studying, including tasks like homework and exam preparation. Moreover, their work is interwoven with pre-set time frames (e.g., for lecture, project, homework) suggesting their work occurs seemingly continuously.

Other student comments move beyond daily schedules to emphasize deadlines. One stated, “Then when it’s the day before the homework is due, the (tutoring room) is packed and all the seats are taken so you kind of have to wait outside” (2YS). Another responded:

There have been days that have just been demoralizing with how much (work) was due for so many different classes. The day after fall break we came back, and we had an exam that night from 8:00-10:00 p.m. We had a lab report that was due at midnight.
We had a pre-lab which was due the next morning – for me by 8:00 a.m. And, we had a homework that was due pretty soon after, and then I had other homework for my tech elective that was also due on that day, and I had to finish my final section (of homework) before I went into that (class) (3YS).

A greater focus on academic activity seems to prevail around these cutoff times – whether related to help seeking, completing assignments, or studying. The amount and pace of activity leading up to a deadline increases and then is followed by some evaluation of student performance (i.e., through grading).

Time and Workload Beliefs. Views of time and workload change as ES students progress through the program. 2YS students articulated concerns about course expectations. One of them commented, “The workload they give you makes it pretty explicit that they (professors) want us to spend a lot of time studying and doing homework” while another remarked, “This year we have to work all the time to be able to be successful.” Ultimately students learn to accommodate the workload demands during their university experience which translates into many hours of academic work. A 4YS student offered, “It’s tough. The material’s really hard. Yeah, I just want to get through at this point.” We also discovered that while ES students mention being “busy,” it is a term used rarely – despite the amount and intensity of their workload. Of the 104 study participants, only six used the term at all, and none used similar expressions such as hectic or harried.

ES majors mention their satisfaction in acclimating to the program. A 2YS student stated, “As the exams progress, you really get to assimilate all of the data that you’ve learned and…realize how much you end up learning over the semester” (3YS). The adjustment proceeds at varying rates during the students’ second year, despite the uptick in workload: “It was basically the workload that surprised me because during the first year I was like, ‘How can a person do more than this?’ And then we come into ES (and) it’s double the amount of workload, and it’s like, ‘How will I be able to manage it?’ And now it’s like, ‘Okay, it’s fine.’” Attitudes generally shift from time and workload toward pride in accomplishment.

Adjustment Strategies

Mastering the Technical Content. Students navigate the program by using various work strategies. They may employ tips from professors and academic advisors that are helpful in “time management” such as “seek out peer help,” “plan out the entire semester (and) put it on the Google calendar,” along with accessing resources (e.g., tutoring rooms staffed by Teaching Assistants). Students routinely work collaboratively. One commented, “I have a study buddy (partner) that I’ll do a lot of the homework with so that we can bounce ideas off each other and…won’t be stumped on one problem forever” (3YS), while another stated, “If I’m on strapped time…I can just ask my friends” (2YS). ES majors also share tips, advising each other. Work and time are interwoven throughout their discussions; the concepts of work and time often carry an implied (or explicit) reference to each other.

A second strategy entails trial and error learning. Delaying assignments can inspire a change in behavior. One 3YS student indicated he learned from the following experience:

The homeworks (sic) were always due on Fridays, and I fell into a peer group that always did those homeworks on Thursdays (at night), and that was never a good idea…You can’t go and ask a TA (then), and the people who are awake doing it are the people who also procrastinated.

Others advocated: “setting more time for preparing for exams” (2YS) or “just choosing to use your time efficiently” (3YS). Maximizing one’s productivity is helpful: “Time-to-benefit ratio – when you have all these assignments, you have to prioritize” (3YS). 2YS students suggested doing homework between classes, giving priority to exams over homework, and considering the student role as a job: “Honestly, you get up, you work an eight-hour day, and that’s, I think, how you ultimately become successful in ES.” A learning curve is
embedded in the identification and use of successful work strategies; once put into practice, students indicate getting better at time management.

**Work-Life Balance.** Time management pertains to all aspects of the student experience:

- It’s *super-fast-paced*. I’m learning everything – a ton of different stuff *each week* – which is good. But, it’s hard to *keep up*…just because you’re so overwhelmed with trying to balance ES with your social life, … family, and all these other parts in your life (2YS).

When possible, students try to integrate areas of their lives together. Many combine studying with socializing: “If I’m not *super time-crunched*, I prefer (studying) with friends, just because I can get stuff done and socialize *at the same time*” (2YS), while others mix extracurricular activities with the social or personal: “That’s like *my extracurricular time* – Baja (a hands-on engineering experience in which students build and race an off-road vehicle). It’s not really…a burden. It’s *my fun time, my getaway time*” (4YS). Another strategy is socializing largely within ES, increasingly evident over the three-year major: “I find it hard to maintain relationships with people who aren’t in a similarly *time-intensive* or difficult major” (3YS). These comments are consistent with survey results in which 44% of respondents (N=194) reported that achieving work-life balance is “always” or “most of the time” a source of stress.

Almost all ES students engage in more than one extracurricular activity, with a high proportion linked to engineering (e.g., racing teams, mentoring). ES majors sometimes have minor concentrations in other disciplines or participate in specialty certificate programs. Most take part in one or more internships, co-ops, or study abroad experiences. They are also involved in university club sports, tutoring, fraternities, volunteer service, religious ministries, and exercising/working out. Such high levels of involvement offer a refreshing alternative to their studies. Yet, the cumulative effect of all these activities can lead to recurring issues. Common 2YS statements included: “I get to *a point sometimes* where I have a *free half an hour*…I’m excited to not have to have anything to do…because I feel like I’m *always* doing something,” or “I don’t think I slept *earlier than 2:00 a.m. or 3:00 a.m.* for the *past two and a half weeks*” (2YS). Survey results paralleled these statements: 65% of respondents (N=194) indicated that they get less sleep than they would like “always” or “most of the time.”

**Learning Now for the Future**

**Time-Sensitive Advice.** We asked study participants for their advice for new ES students. Their comments resulted in 110 suggestions, of which 43% were time-related such as:

- “*Procrastinating will kill you*” (2YS).
- “It’s always better to ask a question *early*, because *then* you’re going to have A) *more time*, and B) …you’re not going to have the anxiety factor” (2YS).
- “From *the time you’re up in the morning*…until whenever you’re done *in the day*,…work that *entire time* and you can take it easy *at night*” (4YS).

Although the remaining suggestions did not explicitly reference a temporality, the vast majority pertained to coursework and studying, in which time could be inferred: “Don’t be afraid to ask somebody else for help” (4YS), “Take old exams…that’s part of surviving here” (4YS), and “When you’re just doing homework, don’t just complete it; try to understand it” (2YS). Such advice can aid comprehension in the present, rather than delaying it.

**The Payoff.** Infused in ES-student comments about their anticipated degree was a sense of self-satisfaction and pride: “A *four-year* degree will really give me focus and confidence and the ability to *get through* a lot of hard things in life” (2YS), “When you *come out*…you are going to be the most qualified engineer that you can possibly be” (3YS), and “300, 350 companies want to come (here) to meet with engineering students – and that’s because (prospective recruits) are expected to be top of their grade, top of their class” (2YS). One 4YS student offered her hopes for ES’ future: “Maintaining the integrity of the program…that
they’re not just letting people skate by with whatever…I have strong standards…I want a school that has esteem because that’s kind of what’s backing me.”

Discussion

On Time Generally

Many writers have attempted the challenging task of defining the concept of time, its dimensions (e.g., sequential vs. synchronized; past, present and future orientation), its attributes (e.g., regularity; sequence), and the ways in which it has been categorized (e.g., “scheduled,” “busy”). Unlike Cheng’s (2017) approach to time, ours is not intended to be comprehensive; instead, it examines time during a particular period in the lives of our study participants based on their perspectives. Narrowing the focus enables us to concentrate on the experience of ES majors in a relatively-bounded ES organizational culture.

ES structure (e.g., schedule, sequencing,) and expectations (e.g., course requirements, professors’ tips) help create frameworks and beliefs for organizing the student experience in the present time and through time. Students undergo this period in their lives subjectively – that is, as individuals (Gershuny 2005; Liao et al. 2013). Yet, the behavior that ES students exhibit is cultural, that is, it is learned and shared, positioning us to understand their behavior as part of a larger system in which time and activity are integral to culture (Hall 1983). ES organizational culture, interwoven with Hall’s concept of monochronic time, is characterized by rigid schedules, concentration on a single task at a time, sequential activities, and efficiency. Activities among ES students, as with ES faculty, are typically compartmentalized, a key exception involving socializing while in study groups or during extracurriculars.

Notable about the ES-student experience, and expanding on Hall’s monochronic time portrayal, is the array of time markers (e.g., “in between classes,” “at night”) mentioned Students use these time markers to signal the sweeping focus time has on their activities (e.g., studying, club involvement) which satisfy ES expectations. These time markers are unlike a typology of time categories (e.g., scheduled time, wasted time) (Liao et al. 2013, Ylijoki & Mantyla 2003, Zucchermaglio & Talamo 2000). Instead, they reference moments both explicitly and implicitly linked with cutoff points (e.g., homework is “due,” exam begins “at 8:00,” a “free half an hour” ends). ES majors become increasingly adept, particularly in 2YS, at managing their activities in relation to mandatory deadlines (e.g., lab report due date), pre-set schedules (e.g., tutoring rooms), and agreed-upon time frames (e.g., study group meetings) (Briody et al. 2018). Cutoff points in a student’s day, week, semester, or entire university experience are a critical mechanism fueling the acquisition of time management skills, which in turn, help students organize their workload, improve their productivity (Starkey 1988) and engage in extracurricular and personal activities.

Time markers also indicate the value students ascribe to their activities. For example, the terms “prioritize” and “procrastinate” repeatedly appeared in our interviews and focus groups. Students advised prioritizing activities (e.g., “exams over homework,” understanding not “just doing homework”) and keeping up with the workload (e.g., “Procrastinating will kill you”), thereby denigrating any delays that substantially shift their focus away from academic work. Prioritizing and keeping up with their studies are cultural rules that ES students share widely with each other. These cultural rules represent time-management advice that has the potential to help students “stay on track” and enhance their performance; over time, they may help students reduce stress and confront academic challenges (Misra & McKean 2000).

On Busyness Specifically

To what extent is busyness connected with ES organizational culture? Elsewhere we argued that busyness is a “defining characteristic of ES organizational culture” (Briody et al. 2019), though we did not define it. When considering the “emic” or insider perspective, we discover a surprising pattern: ES students rarely self-identify as “busy.” Even more surprising, we find a strong tendency among them to augment their seemingly full university days with
additional hours of skill-building extracurricular pursuits in which they relish. Given their crowded slate of activities, ES students seem to meet key definitions of busyness such as having “hectic schedules” (Graesch 2009:85) or facing a “crunch of either speed or activity, or both” (Levine 2005: 356) which stem from “an offshoot of fixed schedules” (364). To understand busyness, Darrah et al. (2007: 257) advise us to examine the “minutiae of other peoples’ lives.” From a layperson’s perspective, students are busy; their activities reflect the regularity in their schedules, the high volume of work, and the degree of variety (e.g., coursework, extracurriculars, internships) – all of which suggest they are indeed busy (Snyder 2013).

However, what might explain why ES students do not explicitly mention busyness in their discourse? First, we wondered if the term busy might mask certain ES-student behaviors. We know that busyness is tied to certain evaluative undertones including an alignment with restlessness, lack of prioritization (Greenfeld 2005), and fragmentation (O’Malley 2005). While these features may characterize some 2YS as they acclimate to ES expectations, this characterization conceals the most salient responses to the ES experience: focus and prioritization. Students’ ability to concentrate on their courses and supplement them with the acquisition of professional skills have their undivided attention. They build their knowledge and skills for a specific purpose – to complete their degree, thereby readying themselves for the workforce. We believe one reason ES students do not self-identify as busy is because they are absorbed in their work. This singular focus, not explicit in Snyder’s (2013) analysis, demonstrates not how busy ES students are, but rather how productive they become.

Second, the literature suggests that busyness has become normative with respect to privileged or higher status groups (Bellezza, Paharia & Keinan 2017; Gershuny 2005, Graesch 2009). For example, busy people are perceived to be more ambitious, signaling a higher demand in the job market (Bellezza, Paharia & Keinan 2017; Gershuny 2005). We suggest that ES students do not self-identify as busy because their ES peers are similarly focused. ES students are largely homogeneous in terms of their work-related behaviors and worldview since they are part of the same ES organizational culture. Indeed, if any exhibited “busyness as a badge of honor” (Gershuny 2005: 287) or were identified as a status symbol based on busyness (Bellezza, Paharia & Keinan 2017), all of them would be. Primary circles of interaction are in ES where a concept like busyness does not serve to distinguish ES students from each other. Regardless of whether outsiders (or readers of this article) view ES students as busy, we can say that

1) students’ attention to their work and learning is singularly focused, not scattered
2) their participation in ES organizational culture unifies, rather than differentiates them
3) their assessment of their experience – from both a technical content and life-skills perspective – has been “worth it.”

Implications

This analysis of time opens up a space for understanding the student experience through students’ own perspectives captured in their discourse. The critical effects of cutoff points for attending lecture, submitting assignments, taking exams, and meeting for study groups signal the salience of time in university education. While such deadlines may create stress for students, they also act to focus attention on the learning tasks at hand. In the end, students often reflect back on this kind of timed-learning process, viewing it as an advantage. Study tips and advice, trial and error approaches, peer collaboration and communitas (i.e., community spirit among ES students – Briody et al. 2018), and engineering-aligned extracurriculars all work in concert to propel students toward their bachelor’s degree. Students may perceive time as a threat (e.g., to keep up with homework, not to procrastinate) as is common in monochronic cultures (Hall 1983), but they figure out how to prioritize, focus, problem solve, and be productive. Faculty should recognize that students are not only trying to learn the technical material and applicable skills of their courses and engineering-related extracurricular activities, but that they are also developing
and refining the process of how they learn best. Continually encouraging experimentation with various learning techniques will help students discover effective strategies for absorbing, mastering, and retaining the engineering content.

As students adjust to the increased workload and pace of coursework as 2YS, their behavior blends in with those around them (e.g., upperclassmen, faculty). This consistency in both behavior and beliefs is a hallmark of organizational culture. Students, like faculty and staff, recognize the “rigor” within the ES and the pride and reputation interwoven throughout. Professors serve as role models, teaching incoming students about their expectations, thereby helping them to acculturate to new demands on their time (Starkey 1988) at this point in their lives. Students are not busy for the sake of being busy (O’Malley 2005). Instead, they are focused on achieving an outcome – their bachelor’s degree – that they believe reflects the blood, sweat, and tears of the productive selves that they have become.

Our goal has been to describe and explain the ways in which students navigate time within an organizational culture, complete their engineering studies, and prepare for the workplace. We use their own statements to depict their experiences. Throughout the four years, ES students build a work ethic that incorporates learning strategies, technical content, and time – all of which get tested and refined in their courses and related co-curricular experiences. Students indicated to us their pride in the ES program for its “rigor,” “intensity,” and preparation for overcoming some of the “hard things in life.” Time – in its various dimensions – plays a critical role in helping them learn to set priorities, work within constraints, and establish the groundwork for future employment.

References


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Disciplinary learning in project-based undergraduate engineering education: the case for new knowledge

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Abstract: Project-based Learning (PJBL) utilises a series of authentic projects which reflect the ‘unit of work’ as experienced in the engineering workplace; is understood to be closer to professional realities and involves the collaborative application of knowledge, understanding and skills. Moreover, it offers curriculum designers a pedagogical approach which moves away from a more didactic, knowledge-led curriculum to a more active, student-centred approach to learning. However, it is often suggested that PJBL in engineering education is more directed to the application of knowledge as opposed to the acquisition of knowledge. This is seen to limit both the learning outcomes of PJBL and the likelihood of students developing both generic skills alongside disciplinary knowledge and technical skills. Drawing on qualitative data collected through observations of PJBL activities and interviews with undergraduate engineering students in situ, we show how students develop their disciplinary understanding through collaborative learning and engagement.

Introduction

Over the last twenty years, Higher Education (HE) institutions involved in engineering education have reflected on their curriculum offer in response to the worldwide call for graduate engineers who have achieved “…the right balance between scientific and technical understanding and their practical application to problem solving” (RAE, 2010:ii). The 21st century engineer is expected to be able to identify as well as solve problems and work across multiple boundaries with people whose specialist and/or cultural frameworks differ from their own (Jesiek et al. 2018; Tilley and Roach, 2018; Graham, 2018). Skills and attributes such as communication with peers, collaboration, team working and problem solving/solution-finding – variously described as ‘soft’ or ‘generic’ skills - have therefore become central aspirational outcomes of engineering curricula alongside the development of disciplinary and technical knowledge (Passow and Passow, 2017). Common features of various curriculum reforms have therefore included more problem/inquiry-led learning using group projects and tasks, with a shift in pedagogy away from a more didactic, knowledge-led curriculum to a more active, student-centred approach to learning. In such learning environments, opportunities to engage
with and evaluate knowledge, rather than memorize factual information, are central (Damsa and Nerland, 2016).

Nevertheless, achieving a balance between the development of critical problem-solving skills and collaborative working whilst also ensuring the development of technical knowledge and understanding remains challenging. To respond to this challenge, HE institutions have had to address at least three troublesome issues. First: the issue of ‘transferability’ in relation to ‘generic skills’. Introducing generic skills and attributes into a revised curriculum does not necessarily mean that once students graduate and enter the workplace they will become ‘better’ communicators, problem-solvers and collaborators. This is because, as Tynjälä et.al (2000) have shown, ‘generic skills’ are highly context-dependent. Second: the development of more student-centred pedagogies to address the disciplinary and technical knowledge requirements of engineering. Third: the pedagogic development of engineering academics in changing curriculum contexts. For many engineering curriculum designers, including the one at the centre of the research presented in this paper, a project-based learning (PjBL) pedagogic approach provides a response to the first two issues.

The rationale for the adoption of a PjBL approach is multifarious. While there are parallels with other inquiry-led learning innovations – particularly problem-based learning (PBL) – the use of the term ‘project’ in PjBL is particularly significant in relation to engineering. This is because project-working has become part of the working life of many, including IT, media and engineering professionals (Hanney, 2018; Guile and Lahiff, 2017). In an engineering context, as elsewhere, the concept of the project team informs the division of labour. Working practice is therefore organised around time-bound projects and teams, which are composed of various multi-disciplinary engineering professionals (and often external non-engineering professionals), focus on problem-solving and solution finding in addressing a given brief (see Guile and Wilde, 2018 for fuller discussion). Hanney (2018:770) also points out that in conceptualising a project team, attention should not solely be directed to the tools, procedures and techniques involved, but also to the recognition that project-working is “… a practice born of a particular set of historical, social and cultural factors.”

Project-based learning can be understood as a pedagogical innovation which is consistent with a social constructivist approach to learning (Felder, 2012) where students work in discipline-specific and/or multi-disciplinary collaborative groups towards a solution to a problem and/or query. This learning context provides students with the opportunity to construct their own understanding through interaction with others, as Duffey et al (2013) have shown in their review of a PjBL module in Electrical Engineering. PjBL aims to offer the opportunity to integrate theory and practice by way of organising learning around a ‘real-life’ and, therefore, authentic, time-bound working issue or problem. In such situations, as Thomas (2000:3) has shown, PjBL not only involves students in constructive investigation, but also enables much more “student autonomy, choice, unsupervised work time, and responsibility”. However, it is often suggested that PjBL in engineering education is more directed to the application of knowledge as opposed to the acquisition of knowledge (see, inter alia, Hall et al 2012; Perrenet et al. 2000) and that this, in turn, limits the learning outcomes of PjBL. It is therefore seen as less likely to offer a learning environment which achieves a balance between the development of generic skills vis-à-vis the development of technical/disciplinary knowledge and skills.

Drawing on data from a collaborate research project: Fitness for purpose: developing the pedagogy of project-based collaborative learning (2017-18), this paper examines the nature of student learning and engagement in discipline-specific project-based learning activities. It questions the positioning of PjBL as more suited to the application of knowledge (described above) and addresses the following questions: a) How do students describe what they are learning? and, b) How does learning takes place in disciplinary-based PjBL activities?

This paper is organised in five sections. Following this introduction, a brief overview of the learning context will be provided. An account of the research design and methodology
underpinning the research is then followed by a discussion of the findings. The paper concludes with some implications for practitioners.

Context

At University College London (UCL) Faculty of Engineering, PJBL has been an integral feature of the undergraduate curriculum since the introduction of an Integrated Engineering Programme (IEP) in 2014. In her global review of undergraduate engineering education Graham (2018) features UCL’s programme and summarises the educational approach taken as having two main components:

- “a common curriculum structure, adopted by all undergraduate programs across UCL Engineering, that is built around a series of authentic engineering projects;
- shared multidisciplinary team projects and Minors, bringing students together from across UCL Engineering.” (2018:91)

We focus here on the first component. In their first and second years at UCL, students experience six discipline-specific PJBL scenarios which often draw on external partnerships and the knowledge and experience of academic staff (faculty) in specific engineering contexts. The ‘series of authentic projects’ are called ‘scenarios’ and take place in one week, full-time, across all engineering departments. They are, initially, designed to contextualise prior learning – requiring students to solve problems and/or develop design solutions to specific issues. The final two scenarios generally reverse this format, exploring the theories and principles that underpin the scenario after its completion (Graham, 2018). The scenarios therefore become increasingly complex and open-ended for students as they progress through the programme. Students also experience two interdisciplinary PJBL experiences in their first year which run over a five-week period across all departments and a further two-week block challenge (How To Change the World) at the end of their second year. In terms of scale, it should be noted that the How to Change the World experience involves 750+ students, 65 partners, 5 cohorts, and a 50+ teaching team (for further discussion see Tilley and Roach, 2018; Graham, 2018).

The PJBL scenarios have evolved over the years of the IEP, are varied and reflect both the numbers of students in the cohort and their respective disciplinary roots. In terms of student numbers, the UCL Engineering programme with the largest student population is Mechanical Engineering, which … ‘has seen its undergraduate intake rise from 45 in the early 2000s to 150 today. The smallest intake cohort, of 25 students, is to the Biomedical Engineering Programme within the department of Medical Physics and Biomedical Engineering’ (Graham, 2018:93). The PJBL scenarios range from ‘designing and building an article of smart clothing for an athlete’ in Biomedical Engineering, to ‘formulating a bioethanol production strategy for the UK capable of satisfying 5% of road transport fuel demand using a given feedstock’, in Biochemical Engineering.

Irrespective of this diversity, the projects can be seen to embed central features of PJBL outlined above. For instance, students are normally given a query or a problem at the start of their activity; the projects are strictly time-bound with interim and final deadlines for feedback opportunities; they require collaborative group work managed by the students with varying amounts of guidance and instruction from staff. Most importantly, student learning lies at the heart of the PJBL scenarios. This is central to the PJBL experience because, as Hanney & Savin-Baden (2013) have argued, if learning is de-centred from the experience, then students are simply engaging in ‘project work’ – not project-based learning. In the case of the former (project work), the outcome (the product; the artefact; the concept) may become the driving factor rather than the learning gains throughout the process.

Theoretical framework

The research design was generally informed by insights from socio-cultural theories of learning and, in particular, the work of Brown et al. (1989) who challenge the ways in which teaching and learning (in all phases of education) has traditionally separated what is learned from the
context and use of learning. In developing the concept of ‘situated cognition’, they argue that over reliance on methods of didactic education has led to a separation of knowing and doing, where knowledge is treated as “...an integral, self-sufficient substance, theoretically independent of the situations in which it is learned and used” (1989:32). In contrast, socio-cultural theories of learning present an understanding of knowledge which accepts that rather than being wholly given, knowledge should be construed as dynamic and emergent in practice. This means that the deployment of knowledge and skills is highly dependent on situational factors. One consequence of accepting the situational nature of knowledge use and development would be that we would be less likely to have students who can, “...manipulate algorithms, routines, and definitions they have acquired with apparent competence, but have no idea what to do with them in a ‘real life’ situation” (1989:34). This approach aligns with the insights offered earlier by Tynjälä et.al (2000) in relation to the highly context-dependent nature of generic skills. Additionally, we draw on insights from broader theories of workplace and work-based learning, including pedagogical approaches to skill development and the nature of knowledge. In these approaches, the opportunity to construct understanding through interaction with others in a social setting is a fundamental aspect of learning (Lave and Wenger, 1991).

Research Questions

The overall aim of the research project reported in this paper was to develop knowledge and understanding of how engineering students learn in the IEP PJBL context. Two research questions framed the research reported in this paper: a) How do students describe what they are learning? and, b) How does learning takes place in disciplinary-based PJBL activities? The questions were addressed through qualitative, collaborative, multi-disciplinary practitioner research (outlined below). In this research, the aim was to generate data from as many instances of PJBL as the research constraints allowed, whilst reflecting the diversity of engineering disciplines in the faculty. The research activities centred on first- and second-year students between October 2017 and March 2018.

Methodology

To achieve an understanding of the ways in which students learn in a PJBL context, qualitative data was collected through observations of PJBL scenarios and interviews with undergraduate engineering students in situ. Observation, informed by the principles of ethnography, enables data to be collected in ‘live’ settings. Data is collected on the ground, in real time, as it happens. Adopting an “unobtrusive observer” role (Robson, 2002:309), the researcher can generate descriptive narratives of the observation setting. Interviews elicit perceptions of feelings and views which cannot be gained by observation alone. Crucially, conducted in situ, they offer opportunities for participants to discuss practices that are being observed. Semi-structured interview questions provided a prompt to researchers for what was envisaged to be a more conversational interview approach. This is because where interviews take a less structured format, they act to make public what Burns (2000:424), describes as the “… private interpretations of reality”. This rationale helped the approach taken to the interviews conducted in situ. Students were engaged in PJBL in groups, and discussions were therefore held with group members – individually and collectively. Following students’ agreement, discussions were recorded and later transcribed. Four of the research team were engaged in gathering data as observers and interviewers. Each of us also led a small group (of two or three) Post Graduate Teaching Assistants (PGTAs) who were recruited from the Faculty of Engineering Sciences. Six PGTAs were recruited from the pool of PGTAs who facilitate learning across all engineering departments. A research methodology training event was provided prior to data collection.

Table 1, below, provides an overview of the disciplinary scenarios that were observed and the interviews that took place in situ. Although not reported on in this paper, in the time frame of
the research, one interdisciplinary challenge was observed over a five-week period between November and December 2017.

Table One: Disciplinary challenges observed

<table>
<thead>
<tr>
<th>Year One</th>
<th>Year Two</th>
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<tbody>
<tr>
<td>Civil Engineering</td>
<td>Biomedical Engineering</td>
</tr>
<tr>
<td>Electrical and Electronic Engineering (EEE)</td>
<td>Biochemical Engineering</td>
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<tr>
<td>Mechanical Engineering (Part 1)</td>
<td>Chemical Engineering</td>
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<tr>
<td>Mechanical Engineering (Part 2)</td>
<td>Computer Science</td>
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</tbody>
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As is the case in any qualitative approach to collecting data by observation and through interview, all the descriptive items were compressed and made manageable through the identification of categories, “analytic schema” (Fielding, 1993:167) or themes. Findings from the research project were initially organized around four key themes. These themes were identified from the outcomes most often associated with innovative engineering curricula. That is, the extent to which students developed skills associated with non-technical aspects of engineering solutions; the extent to which students are able to turn theoretical work into real solutions; the ability to start with the minimum and to identify problems as well as problem-solve (see Lahiff et al. 2018). To address the aims of this paper and, specifically, to shed light on the development of students’ technical /disciplinary knowledge in PJBL, we have focused on findings from the second theme: Turning theoretical work into real solutions.

Findings and discussion

Three main themes associated with the development of disciplinary/technical knowledge and understanding were identified. These themes are: putting knowledge to use in new contexts; learning something ‘new’; and developing knowledge through collaboration. But, as reported elsewhere (Lahiff et al. 2018; Detmer et al. 2018), common learning points identified by students in discussions were related to the development of ‘generic skills’ under the theme of ‘non-technical aspects of engineering solutions’. Communication and team working were most frequently referred to although, for some students, budgeting and working within limited resources also featured in their responses. The following responses from Biomedical Engineering students are illustrative:

“I think definitely communication, because it’s OK that everyone does anything but if they’re not communicating what they’re doing it’s hard for you to know what they’re doing […]. It’s also difficult to know what they’re thinking.”

“In terms of soft skills… I think we’ve definitely worked on communication and different methods of keeping everyone up to date and in the loop, including like using Google Drive, setting an action plan each day…”

“We looked at what we were given [budget/resources] because we needed to do something that was viable […] We’d used flex sensors and pressure sensors in previous labs so we knew how they worked, so they wouldn’t be wasted [if we spent some of our budget on them]…”

However, what also emerged from the data in relation to the development of generic skills was the importance of the disciplinary context to both the development of communication skills and team working. In single discipline scenarios, students explained that they thought that they ‘spoke the same language’ with disciplinary group members because they not only shared technical knowledge but also a discourse and understanding of the ways of working in the discipline. Their learning was, therefore, consistently framed by the disciplinary context.
Putting Knowledge to Use in New Contexts

Turning attention to the development of disciplinary/technical knowledge per se, students spoke specifically about the ways in which the PjBL scenarios provided opportunities for the application of knowledge to practice. Across the disciplinary groups, students talked about the ways in which the PjBL scenarios provided a way to contextualize their disciplinary learning. This is unsurprising of course; some scenarios were developed specifically to provide this opportunity (see context, above). Nevertheless, the data offers an insight into the ways in which disciplinary learning develops, *as it is being developed*, and how, when faced with a real-life problem, students develop their knowledge and understanding. To illustrate, when asked what technical knowledge they brought to the scenario being observed, a Biochemical student reflected:

> “I guess it’s familiarisation with the material that we learn in class. Because I guess in lectures you kind of absorb it but when you actually apply it and you kind of think of all the assumptions […] it’s better than like sitting in a room, a lecture room, listening to pure theory things. Because you work through it and you learn better…”

Similarly, an Electrical and Electronic Engineering student reflected:

> “Yeah, I mean I’m learning a lot. I know things that I didn’t know and I feel like I’m really understanding the equations we’re using. The thing is that [because] we are applying these in real life, we have to figure out what we are measuring [when using equations] … like when we did the problems [in lectures]..we just take like what they tell us, but here …. I’m really understanding what we are doing, and it’s good.”

Across all the scenarios, irrespective of the relative complexity of the scenarios and the disciplinary context, the value of the PjBL approach to the development of understanding is acknowledged. The following response from a first year Electronic and Electrical Engineering student is illustrative:

> We learn more because the lecturer doesn’t tell you how to make an electromagnetic force; they just tell you some theory. And the scenario kind of helps us to put it into practice and to measure some parameters by ourselves. So, I think it’s more important than the lectures.

However, there was also evidence of disciplinary learning which moved beyond theory and into developing understanding of the practice of engineering. For example, Mechanical Engineering students experience two linked scenario weeks in their first year. During the first week they focus on a design process which is followed five weeks later by a ‘build’ scenario. As with other students, they fully appreciated the value of the PjBL experience but they also identified the contribution the PjBL scenarios made to their sense of ‘becoming’ a Mechanical Engineer as the following quotations illustrate:

> Because like it’s about using what we’ve learned so far and the planning process and everything about the design process to actually make something that we can feel and touch and that actually works…

> [In this second] scenario, like we actually build something! So, like to me, it felt like I was doing engineering, it didn’t feel like I’m doing an actual science degree!

Learning something ‘new’.

Across the disciplinary scenarios, some students were asked whether they were learning ‘*anything new*’ and left to define what that meant for themselves. What is reported here is a selection of the various ways students described ‘new learning’ in relation to technical knowledge and skill. For second year Computer Science students, for instance, there was a consensus that a lot of the technical skill development was ‘new’ and similarly for Biomedical...
students who had been told they needed to use a new coding system. The first student quotation is from computer science, and the second from Biomedical

“Well…a lot of the stuff that we’re doing is new, so it’s connecting to new systems that we haven’t seen before and providing sort of features that we haven’t tried before. So, both in own areas of expertise and in other areas we’ve sort of learnt new things.”

“This is Arduino [coding] and we’re just given it! [Its] daunting to have to learn it, but we actually learn a lot because we make mistakes….”

Being aware of learning ‘something new’ in the PjBL scenario was also the case for some Chemical Engineering students who were asked whether they were applying what they had learned before to a practical context. The first response is unequivocal, while the second takes up the notion of ‘newness’ given differing contextual conditions:

“No, Not really. I think it’s quite new, like the materials that we’re doing you know it’s not really like what we’ve done last year. Because last year we did a lot about pharmaceuticals […] But this year it’s really more about working through with like this new area….”

.. “a lot of the stuff is new and you’re putting that into a newer context too, so you need to do research on that to make everything work.”

Finally, in Civil Engineering, some students who were interviewed whilst they were completing some mathematical calculations required for the scenario were asked whether they were learning anything new. One student responded directly:

‘From knowing nothing to finding a way to figure out all this, then you must learn something!”

Developing knowledge through collaboration

One of the assumptions of a social constructivist approach to learning is that through engagement with others knowledge is developed both singularly and collectively. This is also the case in the workplace: the key to successful project-working is often seen to be successful collaboration. In the PjBL scenarios student groups, depending on size, often shared out areas in need of investigation and came together throughout the week to combine their efforts. In the following illustration a student from Civil Engineering describes the ‘knowledge gains’ in the division of tasks:

“If people are working on like let’s say, geo-technics they are getting knowledge of that part. But if you’re doing tunnel structures you’re getting knowledge of that part, you know. Also standards, what sort of materials you want and so on”…

When asked whether individuals then came together and shared their developing knowledge, the overwhelming response was: “Yeah we do.” There was a similar response from students in Computer Science. When asked whether sharing of knowledge occurred, one group member responded:

“Yes…especially in the integration part, because you cannot just integrate with the others, you have to understand what he has done. You have to understand everything. You cannot just integrate some part without understanding the work”.

The recognition of the importance of sharing learning was common across most of the scenarios. In part, this might be explained by the way in which some academic staff have ensured that group members share their knowledge gains through the promotion of more collaborative rather than simply co-operative group membership. This has been achieved
through structured activities and assessment practices. For example, if students are being assessed on presentations, any member of the group can be called upon to explain the content of the presentation. This was seen as particularly important for groups of more than four.

Other insights into developing knowledge through collaboration highlighted the value of collective problem-solving. There were a number of instances of this. The first illustration is from Mechanical Engineering and the second from Biomedical Engineering, where various sensors were being tested.

"With the design process we found there’s been an ongoing [problem] situation for us because every time we thought we’d completed a design we had another flaw came in our way. And yeah just multiple problems that came up and together we just had to find a way of solving them."

"It was sort of a trial and error scenario where we found that it wasn’t working as well as we’d hoped it would be. We brainstormed, we came together as a team and talked about how we might improve the functioning of the device and once again we tested them and we found that this one worked the best."

In summary and without underestimating the challenges faced in collaborative working, students across disciplinary scenarios discussed the benefits of collaborative engagement and were also able to identify the utility of collaboration for future working practice.

Conclusions and implications.

This paper has drawn on our research into engineering students’ learning in PjBL contexts. By interviewing students in situ as they worked through their respective scenarios, we have seen not only how students develop their generic skills in a disciplinary context, but also how PjBL can provide a learning environment in which disciplinary knowledge and technical skills flourish. Our argument is that by introducing PjBL, it is possible to achieve a balance between the development of generic skills and the development of technical/disciplinary knowledge and skills. However, it is important to state some caveats – both theoretical and practical. The first of these relates to understanding knowledge.

Socio-cultural theories of learning understand knowledge as dynamic and emergent in practice, with deployment of knowledge and skills dependent on situational factors. Separating knowledge acquisition from application therefore creates a spurious and unhelpful dichotomy – not only for engineering educationalists but also for students. As we have shown here, students continue to/develop their understanding of key concepts and disciplinary practices as they ‘put their knowledge to use’ in new situations through collaboration with others. Secondly, the learning potential of PjBL activities can only be maximized if it is understood as being a pedagogic tool. In other words, students are not ‘doing projects’; they are engaged in project-based learning activities. These activities are simply framed as projects due to the ubiquitous nature of project-based working practice in engineering and the desire to replicate this ‘real-life’ phenomena in HE. Thirdly, through the discussions with students in situ reported here and from our knowledge of the IEP scenarios and their respective development, students need the opportunity to reflect on their learning experience and record their own development. These reflections can be built into the experience and, indeed, become part of individual assessment, if desired. Fourthly, the PjBL scenarios reported here are actively mediated and assessed informally and formally in various ways by academic staff and PGTAs in engineering. Ensuring that staff who mediate learning in PjBL contexts are sufficiently confident in doing so requires appropriate professional development opportunities. This does not necessarily mean the development of formal continuous professional development (CPD) opportunities. Rather, our starting point is to engage with IEP staff to share their experiences of the development of expertise in this area. Finally, whilst of necessity a selection, we have been able to share some engineering students’ experiences of learning in PjBL contexts in their own words whilst they were engaged in PjBL activities by adopting a qualitative approach to research. The value of
adopting this approach has been enormous. We would encourage others within engineering education to do so.

References

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The Impact of Capstone Design Courses on New Engineering Graduates Preparation for Teamwork: A Mixed Methods Investigation

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Abstract: The present study is an investigation of the transition from Capstone design teams into teamwork settings in participants’ first job after graduation. Research participants were followed from graduation through the first three months on the job via a series of interviews and surveys. Results indicated that the majority (82%) of participants felt prepared for teamwork on their first job, but that there were incidents where graduates felt less prepared for the transition into work teams and these were explored in depth. The results of this analysis revealed a variety of mismatches between Capstone and workplace teams and leads to a call for deeper investigation of team cultures in both settings to better prepare new graduates.

Context

Capstone Design courses have become widespread in US engineering education settings and are spreading globally due to common accreditation practices and agreements for the transfer of licensure (ABET, 2019). Despite their prevalence, less is known about the impact of Capstone courses on the experiences of engineering graduates who enter the workplace. Previous work has identified a skills gap in new engineering graduates’ capacities and the demands of the workplace including deficits in project management and design (Dutson et al. 1997).

The present investigation delves into this transition out of Capstone via a longitudinal mixed-methods investigation of recent graduates from four Capstone programs at separate universities in the US. In this investigation, study participants are followed from graduation and into their first job via a series of surveys and qualitative interviews.

Data were collected across a broad range of skills, but the present study investigates the development of teamwork skills and the transfer of these skills into their first team experiences in the workplace. The investigation looks across the first three months of employment for the first cohort of study participants, and then delves more deeply into the experiences of those new graduates who were challenged by their first work team and felt less prepared by Capstone for their initial team experiences.

Research Question

The present study investigates the following research question: How do students’ experiences in Capstone Design Courses contribute to entry-level preparation for teamwork, and to what extent? This study is important for engineering education as Capstone Design courses are increasingly relied on to bridge this gap between university and work and they...
are often resource-intensive endeavours involving multiple internal and external stakeholders that increasingly stretch across both semesters of students’ senior year. With all of these resources committed, it is important to understand the impact of these courses on graduates’ transitions to the engineering workplace.

**Theoretical Context**

For this study, we use the Communities of Practice framework to understand how engineering organizations function, and to therefore understand what learning is necessary in order to participate in engineering organizations (Gilbuena et al. 2015). The framework describes three main features of any Community of Practice, which should also be present in most (if not all) of the engineering organizations that US engineering undergraduates enter after work. Those three features are related to the culture that is established within the community of practice: (1) “joint enterprise”, a recognition of the goals and purposes that the community must work together to accomplish; (2) “mutual engagement”, the back-and-forth creation of meaning by members of the community who work with or alongside each other; and (3) “shared repertoire”, an understanding of the patterns of activity and learning that allow for work to get done, which is firm but can be renegotiated.

On a surface level, Capstone is meant to prepare students for these Communities of Practice by creating contexts that resemble the contexts of work. In broad strokes, Capstone accomplishes student preparation for work because it puts students on teams that must negotiate decisions amongst themselves under constraints like budget and time (mutual engagement). It encourages them to use similar practices such as PowerPoint presentations, and software, such as SolidWorks, that they might use at work (shared repertoire). It invites them to shift their priorities from having high test scores and grades, to purposes like minimizing cost of a product, or performing rigorous and accurate tests of prototypes (joint enterprise).

Using this Communities of Practice framework, we can more deeply investigate the sociocultural learning needed to participate on teams at work. Gilbuena et al. (2015) describe multiple aspects of teamwork learning as being necessary for participation in the industry Community of Practice, such as:

- being aware of the strengths and skills of other team members
- distribution of labour, coordination of work with other team members
- conflict management

Importantly, within the Communities of Practice framework these aspects of learning are contextualized. Participants will not need to learn “conflict management” in general, but rather the specific styles, methods or strategies of conflict management that engineers engage in at work. Successful transfer of teamwork skills from Capstone will involve learning “how to do teamwork like an engineer” while still enrolled in the course. As such, this study investigates cultural differences between Capstone and work, in addition to instances where participants feel unprepared or ill-fitted for work because of the ways they learned to do teamwork.

**Methodology**

The data for this study comes from a larger study, the Capstone To Work project (Gewirtz et al. 2018). This project employed a sequential mixed-methods analysis, collecting data from engineering students starting before or during graduation and continuing over the course of the first three months of employment. The project also collected data past the first three months, into the first year of employment but this data is not used for this particular study.

Participants were recruited from 4 institutions from 3 different regions of the United States (Southwest, Southeast, and Northeast). Participants came from 3 mechanical engineering programs and one engineering science program. The programs ranged in size from 20-30...
students per graduating class to larger programs with over 350 students per class. Each program included (but was not limited to) industry-sponsored projects, and had teams of generally 4 to 6 students. Study participants were 62 students who consented to the study and shared data in three forms: surveys, journals and interviews. Journals were not used for this study and so will not be discussed.

Surveys were sent to participants weekly for the first three months of work, totalling 12 surveys. Each survey asked participants about whether they had participated in various work activities that are also practiced in Capstone (e.g. engineering calculations, prototyping & testing, team meeting), and how prepared participants felt they were for those activities on a 7 point Likert-type scale with choices ranging from completely unprepared (1), to completely prepared (7), with the middle option (4) being “neither prepared nor unprepared.” For this study, participants’ answers to the “team meeting” activity on the survey were probed.

The semi-structured interview protocols probed participants’ experiences in their engineering environment (university or work), including their responsibilities, challenges and accomplishments, definitions of engineering, and perceptions of themselves as engineers. The initial interview used a common protocol for all participants. All subsequent interviews used a common base protocol, but then prompts tailored for each participant to follow up on previous data collection; for example, the three-month interviews explored experiences reported in the participant’s weekly surveys. This approach allowed us to maintain a general set of questions across participants for comparative analysis, while also exploring individual experiences in depth. It also allowed the interviewers to build a rapport with participants over time. All interviews were transcribed verbatim and identifying data was removed. Survey data were collected weekly for the first three months of employment, and then participants were interviewed again.

For quantitative data analysis in this study, survey data were averaged across the first twelve weeks of employment. Then, participants who scored a 5.0 and below (slightly prepared) on the seven-point scale were parsed and available interview data for these participants was explored to investigate challenges associated with transitioning from Capstone team experiences to team meetings at their first post-graduation job.

For qualitative data analysis in this study, narrative analysis techniques were used. This type of qualitative analysis is based on the premise that narratives are a natural way that people construct meaning. During semi-structured interviews, the interviewer and interviewee co-construct narratives together. Interviewees share experiences as part of an authentic connection with the interviewer, characterized by interviewer curiosity and interviewee reflection (Pawley, 2009). From the collected data from selected participants, the researchers reconstructed participant narratives with direct quotes from the interviews with participants. For each participant, two researchers read through all transcripts, and selected data to represent a condensed narrative from the participant’s own words (Kellam, Gerow, and Walther, 2015).

Findings

Teamwork (as defined by participating in team meetings) was the most frequent activity reported on the weekly surveys. 56 of 62 participants (or 93%) reported meeting with a team in their first 12 weeks of work. Of all surveyed activities, participants perceived themselves as most prepared to meet with their teams, with 46 participants (or 82% of participants reporting teamwork) reporting either moderate or complete preparation on average across the twelve weeks, scoring greater than 5 on the 7-point scale from the survey.

Of the 10 participants that reported a 5 (slightly prepared) or less regarding their team meetings preparedness, 6 participated in 3-month interviews. Of these 6, 4 narratives are constructed below from participants first two interviews across three months, indicating why they may have been unprepared for team work after Capstone. Table 1 shows the 12-week
average “Team Meetings” score for the 4 participants who felt unprepared when they transitioned to the workplace.

Table 1: Team Meetings Average Score for Participants who felt Unprepared for Teamwork

<table>
<thead>
<tr>
<th>Participant</th>
<th>‘Team Meetings’ Avg Score out of 7</th>
</tr>
</thead>
<tbody>
<tr>
<td>1105</td>
<td>5.0</td>
</tr>
<tr>
<td>3147</td>
<td>4.3</td>
</tr>
<tr>
<td>3148</td>
<td>4.5</td>
</tr>
<tr>
<td>4138</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**Participant 1105**

[Excerpts from the initial interview at graduation]

*We are a (Capstone) team of nine which is a pretty big team, and it’s kinda tough to manage because obviously all of us are peers, and then we meet with our TA once a week, but that doesn’t really give us a lot of structure.*

1105 felt his Capstone teammates were not motivated enough, and didn’t take responsibility for parts of the project.

*If there’s a problem, they let it sit until we have a meeting, and they’re like, “This is a problem.” When they found it maybe the day after our last meeting*

Whenever [our TA] would tell us stuff to do, usually everyone was kinda good and they’d work hard to get it done, but if somebody else on the team was like, “Hey, we need to get this done” there wasn’t that same motivation.

The team waited on their TA for direction, but didn’t give the kind of feedback 1105 hoped for.

*Our TA didn’t play a big role in helping with any of our design stuff. He would occasionally have hints and suggestions, but for the most part we would meet with him once a week and he would say, “Okay. You guys either made good progress, or you guys need to pick it up a little bit.”*

Work is a different scenario. 1105 works alongside his colleagues, but not with them. His boss depends on his work, and he relies on the fabrication department for his own work, but each engineer has their own projects. In his first three months, he asked colleagues a lot of questions, given their years of experience.

[Excerpts from the 3-month interview]

*I sent one drawing of my design through fabrication because I wanted to see if everything would fit. And my boss was like, “Oh, no, it’s gotta get done. Send it all through.” Then it didn’t end up fitting, so we wasted like two sheets of metal. The guys in fabrication were all huffy and puffy because we wasted two sheets of metal.*

Regarding his relationship with his boss, he often feels he is reining him in, “handling” him.

*His sense of reality on some stuff is a little skewed, how fast it's done. A project will start, and it'll have started a month ago. I traveled for four days out of one week and two days out of the other week and another two days this week. Then that month isn't nearly as long as it seems when you're out of the office half the time. That's something he never really gets.*

*He’s very good with customers and with the design work. He just takes a little handling.*
Part of 1105’s success at work involves negotiating work with his boss, a skill he didn’t develop with his TA in Capstone.

*if he starts yelling about something, obviously I take it to heart, but I try not to take it personally because it's just his reaction to things is usually big. I think I can learn to handle him a little better. He's a very serious dude. But I think it's getting better...I'm gaining an understanding of what needs to be done, so if he comes in, like before a trip, and asks if I've done xyz...I'm more like, “Oh, yeah, x and y are taken care of. Z is either under process or we couldn’t do it because of this.”*

**Participant 3147**

*[Excerpts from the initial interview at graduation]*

*I don't like to consider myself a natural born leader, so it was putting myself out of that comfort zone and learning to step up for the (Capstone) team 'cause none of my team members wanted to be the first (leader) either.*

3147 was on a team of four women, and her program rotated leaders every few months during the project. She felt overall that her team worked very well together.

*We're kind of like on the same page of like how we all worked, and we're very transparent with each other. So for example, if someone was overwhelmed with homework and was just like stressed out and like acting a certain way, we were all understanding that that was... like it wasn't something personal or like something that we were in control of. But just being mindful of that person...*

She did feel like she was too much of a pushover, reflecting on her experiences as project leader.

*Whenever someone told me like "oh we should..." like I wasn't strict on deadlines that we had to meet. So then a lot of our tasks or a lot of our deadlines kept being pushed back, and I wasn't stern enough or... I didn't hold my ground in terms of keeping those deadlines…*

*I would try to be a little bit more stern and assertive about certain deadlines that we had to meet or what I thought would have been best for the team in terms of the project and the timeline of the project.*

At work, 3147 is in a different context as a liaison between multiple departments. She receives pressure from her executives, and needs to apply that pressure to teams of engineers or colleagues in other departments.

*[Excerpts from the 3-month interview]*

*I was trying to help a different team ship out a product and because I had experience with the customer that we were dealing with, I knew there were certain access things that we had to include with the products that would keep the customer happy. So I intervened and I made sure that those coupons were included or at least built for them to ship out with the pack and I had a co-worker who was really reluctant in sending out those parts. I actually had executive people say, "No, you need to ship these out." … making sure that whatever action that I take, even if it doesn’t necessarily make another person happy, that they still benefit the company and the customer as a whole.*

She wasn’t sure that other departments knew what her department did, and they sometimes got dumped on with miscellaneous work.

*I think they understand what I do as my position, but I don't … think that they know what my group does.*

She felt that her capstone experiences were a both a benefit and a detriment.

*Coordinating how to do things and keeping that in mind definitely helped me hear, understand and try to negotiate time with the other departments that I have to work with,*

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because they're so swamped with other things and because we're not necessarily a priority. Trying to convince them and trying to make it a lot easier for them to take us in their responsibility is something that I guess I learned through the (Capstone) design clinic as well... I was very fortunate to have a (Capstone) group that was very considerate of each other and we never necessarily had any excuse or anything that hindered our relationship as a whole.

I wish that I ... Don't wish, but I think that other teams within my (Capstone) year probably have more experience and probably know how to handle (conflict) a lot more than I do.

In the end, she did feel that her non-assertive approach could be an asset.

My experience working with women engineers is very different compared to working with male engineers... I really think they're probably a lot more used to people being assertive and forcing things on them, and they appreciate the fact that there's someone who's willing to negotiate and actually understand what their other obligations are instead of being like, "No, you have to do this because I say so." Like understanding that they do have obligations, and being able to accommodate to their needs as well.

Participant 3148
Talking about her responsibility at the workplace, she underwent training with a software which wasn't useful and had to learn the software on her own. She isn’t given enough responsibility in terms of client meetings and leadership. She specifically blames her department and co-workers and in one particular instant while describing her responsibilities she mentioned,

[Excerpts from the 3-month interview]
No, I feel like I shut up and am told what to do and I go home.

She further describes the reason why she doesn't like the job.

The reason I started talking with this company in the first place is because I actually wanted to be on their energy team. I wanted to direct with energy and the need was in mechanical, so they hired me on the mechanical (team), which is funny because then I showed up and they have nothing for me. But anyways, the way the whole industry works is just so convoluted, and it feels backwards, and it seems problematic and there are too many egos. And I'm really finding that what I'm interested in is not this. Because I'm just like, there's nothing interesting about my job to me.

She described the difference with work and Capstone team culture

I think one of the really big differences between work and Capstone is that, well two really big differences. The first is that with Capstone, my team members were all emotionally invested in the projects, like the senior project, so important. We're all working really hard, there's just a lot more behind the motivation and we were also working on it on weekends, late at night, all of the time.

Versus at work it's like, I'm working on three projects on different stages and we go home and it's over, we don't live with each other, we don't run into each other on the weekend. No one plans to work on anything over the weekend unless they really are in trouble and it's like, oh no, why did you come in on the weekend? So, I think the emotional investment and the co-worker boundaries are really different from Capstone.

I think everyone gets way too close (in Capstone). And I don't know if that's unique to that or not but yeah. That is nothing like the real workplace and so that detracts from the experience, but it was different in work- too professional.

Participant 4138
In Capstone, he had heavy teamwork-related responsibilities.
[Excerpts from the initial interview at graduation]

My role was communication director, so I learned a lot about when it's necessary to get a lot of people included in a conversation and what kind of different communication styles are appropriate for a conversation. When is it appropriate to set up a meeting as opposed to set up a phone call or just email someone or whatever? I was being sensitive to other people's time, other people's responsibilities, and choosing communication methods accordingly.

In the follow-up interview, the participant describes their more technical team role and responsibility in the workplace.

[Excerpts from the 3-month interview]

We were supposed to test a website we were developing. I was supposed to test the website. That was a little bit challenging because I was the only tester for it primarily. The one other tester was experienced, but he had other meetings he had to attend. So, I was designated to be the tester for that project, and there was a steep learning curve I had to go through, but fortunately some of my previous internships helped with that.

The participant went on to describe the difference between work and Capstone in terms of team meetings

Capstone didn't necessarily prepare you fully for having Skype calls every day. but it was the first kind of Skype meeting that you had. It was a gradual desensitization to Skype calls. (Capstone) was like a little peephole that I looked into in the world of Skype calls, and then once I got into work it was like this giant window of Skype calls. Yeah it was different.

Discussion and Conclusions

While quantitative results indicate that over 80% of engineering graduates are prepared for teamwork in their first post-graduation job, the qualitative results illustrate the plight of a few participants regarding what it means to be less prepared for teamwork once entering the engineering workplace. The experiences of each participant, and how their teams are structured in Capstone and the workplace, vary considerably. From the perspective of the Community of Practice framework, the teamwork culture that participants are challenged to integrate themselves into is not uniform and there were differences in the Capstone and work cultures in terms of how the joint enterprise, mutual engagement or shared repertoire were defined.

Each participant faced a different teamwork challenge that left them feeling unprepared, whether that challenge was conducting teamwork activities at a distance (4138), unfamiliar co-worker boundaries (3148), representing and pressuring departments (3147), or the need to rein your boss in (1105). There is no one teamwork challenge every participant had in common. However, there does seem to be something in common between each of these participant’s experiences, which can further explain their unpreparedness. Each participant demonstrates, through the narratives that unfold in the Capstone and then work context, a shift in the culture of teamwork. In general, each participant indicates that work culture is significantly unlike Capstone in some contexts, and that the culture of Capstone did not prepare them for work because of the difference. In general, participants were unprepared for teamwork because the teams functioned in an unfamiliar way, not because they lacked any universal teamwork skill.

To further examine the participants’ narratives through this lens, we can discuss the experiences of participant 3148 (in the interest of page length, we limit our in depth discussion to only one participant). A visual representation for participant 3148 was made to illustrate her transition from school to work, shown in Figure 1 below. During the Capstone design phase, she experienced interactions with her Capstone team members beyond work hours and outside of work places which resulted in closeness and strong interpersonal relations among the team members.
When she transitioned to the workplace, her interaction with the team members was professional and only during work hours. There was no interaction among the team members outside of the workplace or after hours. In addition, she needed to interact with her supervisor in the workplace individually, whereas during Capstone design, she only experienced group interactions with her Capstone design advisor. This indicates a shift in culture, in particular, to use the Communities of Practice framework, a shift in mutual engagement (Wenger, 1998). Engineers “do not cease to be [engineers] at five o’clock” (Wenger, 1998, p. 57). The way that employees engage with each other at work is different enough from the engineering teamwork she learned in school to make her feel unprepared, to make her question whether she belongs. In the end, she feels it would be preferable if there were no after-hours interactions in Capstone, as that would serve as better preparation for the world of work. The desired change is not necessarily part of the curriculum, or a missing skill at work, it is a change in the engineering culture she belonged to while in Capstone.

These result affirm prior studies of engineering social climate and socialization. Engineering students develop an understanding of themselves in relation to their team (Tonso, 2006), which may not match what they experience at work. Newcomers are challenged to engage in teamwork activities at work (Yasar et al., 2007) that they may or may not have experienced in Capstone.

**Recommendations and Future Research**

Ultimately these findings have a few implications for Capstone education for engineering teamwork. The first implication would be that the Capstone programs investigated left the majority of participants feeling prepared for teamwork at their first job after graduation. This can be viewed as a type of endorsement for the benefits of Capstone education which often
contains much of the teamwork training in an engineering curriculum. However, there were mismatches between Capstone and workplace cultures that left participants feeling less prepared. Furthermore, participants felt unprepared in different ways. This also implies that there is not be a universal kind of engineering teamwork to prepare for, although that is uncertain given that this research is in a preliminary stage and analyses the experiences of a small group of people.

The findings suggest that future work should investigate the variability of teamwork culture both within Capstone and workplace contexts to better determine how students can be better prepared for their new Community of Practice and where training needs in Capstone should transition to socialization needs in the workplace Communities of Practice. Multiple contexts of engineering teamwork may exist in the workplace, and these may be the cause of unpreparedness for certain graduates rather than a lack of Capstone preparation. Finally, these results suggest that teaching students to recognize and contribute to multiple valid engineering teamwork cultures in Capstone may be the most appropriate approach for workplace preparation; more research would need to be done to be sure.

References

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Toward a typology of the sociotechnical in engineering practice

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Abstract: There remains a surprising lack of empirical research on the day-to-day work experiences of engineers and other technical professionals. Nonetheless, a growing body of scholarship in engineering studies and allied fields has revealed that engineering practice can be viewed as a kind of sociotechnical performance, with many job tasks requiring technical expertise as well as extensive social interactions and negotiations. The goal of this paper is to offer preliminary insights toward developing a typology of the sociotechnical in engineering practice. Analyzing interviews with early career engineers, we present our findings organized around three themes: 1) learning in engineering practice, 2) engineers as sociotechnical gatekeepers, and 3) sociotechnical interactions with boundary objects. These findings have implications for engineering education by demonstrating the need for learning activities that mirror the engineering workplace.

Introduction

While engineering is known to be a highly sociotechnical profession (e.g., see Leydens & Lucena, 2017; Williams, Figueiredo, & Treveleyan, 2013), prevalent ideologies in Western cultures such as social/technical dualism, depoliticization, and meritocracy help maintain a perceived separation of the “social” and “technical” in engineering education and practice, and with the “technical” aspects of engineering often holding higher value (Cech, 2014). These ideologies impact our conception of engineering work, what engineers do, what we consider as “real” engineering, and therefore what we teach in university engineering programs. As many observers have noted, engineering degree programs – especially at the undergraduate level – tend to focus on closed-ended and decontextualized problems (Buch & Bucciarelli, 2015; Leydens et al., 2018). This mismatch between the technical focus of the curriculum and the sociotechnical complexity of actual engineering work means that students are often unprepared for the reality of engineering practice and may be dissatisfied when their job roles are not mainly focused on purely technical challenges (Treveleyan, 2014).

The sociotechnical aspects of engineering practice may also prove to be more intellectually rewarding. Treveleyan’s study of engineers in Australia found that experienced practicing engineers who “stuck with it for a decade or more, had mostly realized that the real intellectual challenges in engineering involve people and technical issues simultaneously. Most had found working with these challenges far more satisfying than remaining entirely in the technical domain of objects” (Treveleyan, 2014, pp. 49-51). An improved understanding
of the realities of engineering work can support recruitment and retention of diverse engineers by managing students’ expectations and showcasing how they can positively contribute to the ambiguous, open-ended nature of problems often faced in the workplace.

In engineering education, there have been calls to reform curricula which traditionally prioritize the engineering sciences and technical skills while downplaying and segregating other kinds of professional skills that are essential for the effective practice of engineering, such as problem definition and communication (Downey, 2005). Further, researchers and educators are developing interventions and assessments that aim to enhance and measure sociotechnical reasoning and thinking in engineering students (Cohen, Rossman, & Sanford Bernhardt, 2014; Heymann, 2015; Johnson, Leydens, Moskal, & Kianbakht, 2016; Leydens et al., 2018; Mazzurco, Huff, & Jesiek, 2014; Nieusma, 2015). Engineering-for-Social-Justice (E4SJ) has also been proposed as an avenue to engage in sociotechnical ways of knowing across all elements of the engineering curriculum, including engineering design, engineering science, and humanities and social science courses (Leydens & Lucena, 2017).

In engineering practice, the interdependence of the social and technical is additionally reflected in numerous empirical workplace studies that shed light on different elements of “doing” engineering work (Lagesen & Sorensen, 2009; Rooney et al., 2013; Styhre, Wikmalm, Ollila, & Roth, 2012; Trevelyan, 2014). These studies challenge us to think beyond the “dualism of the social and technical” and consider “a complex distribution of skills and concerns” (Lagesen & Sorensen, 2009). Conceptual and theoretical frameworks are needed to help us think through these complexities and inform research and training efforts focused on engineering education and professional practice (Trevelyan, 2013). For instance, a practice theory lens was used to investigate the unstructured and informal learning of experienced engineers in an Australia, highlighting “key aspects of practices as embodied; materially mediated; relational, situated and emergent” (Rooney et al., 2013, pp. 271–272).

Nonetheless, we are aware of few if any efforts to more systematically identify the many different kinds of sociotechnical practices encountered when doing technical work. The main goal of this paper is to offer preliminary insights from our own empirical data about different types of sociotechnical interactions that occur in engineering practice. We first present an overview of our methods, then describe three themes of sociotechnical practice: 1) learning in engineering practice, 2) engineers as sociotechnical gatekeepers, and 3) sociotechnical interactions with boundary objects. These themes inform our efforts to develop a typology of the sociotechnical in engineering work. The findings have implications for engineering education practice and pedagogies, as well as for diversifying the engineering workforce.

**Methods**

This research extends a previous study of boundary spanning experiences among early career engineers working in the U.S. and employed by large, multinational manufacturing firms (Jesiek, Mazzurco, Trellinger, & Ramane, 2015, Jesiek, Trellinger, & Mazzurco, 2016, Jesiek, Trellinger, & Nittala, 2017). The researchers conducted 33 total interviews with 29 early career engineers, including students who had completed or were completing internship or co-op appointments, and engineering professionals in their first years of full-time work. Four of the participants were interviewed twice, i.e., before and after starting full-time employment, to glean further insights about the school-to-work transition. We also conducted interviews and collected reflection data from 6 students completing internships or co-op rotations. All data was collected following approvals for human subjects research.

Of 29 total participants, 16 (55%) identified as male and 13 (45%) as female, 21 (72%) identified as White or Caucasian and 8 (28%) as another race or mixed race. The participants held or were completing degrees in various engineering fields, with mechanical and electrical the most common. It is important to note that our sample included more female respondents as compared to the wider population of engineers, i.e., about 45% of our participants identified as women versus a U.S. national figure of 14.5% in 2015. Our dataset
was also overrepresented with those identifying as Caucasian/White, comprising 72% of our participants as compared to a U.S. national figure of 63.1% in engineering in 2015 (National Science Board, 2018). In order to “shift the default” (Pawley, 2017), we are explicitly making visible and acknowledging the presence of “whiteness and maleness” in our study.

Using a thematic analysis approach, a codebook was developed to identify boundary spanning activities (e.g., coordination, building and maintaining networks, etc.) and boundary types (e.g., organizational, time and space, demographic, etc.) in our data. Development of the codebook was in part informed by a previous systematic literature review on boundary spanning and engineering (Jesiek, Trellinger, & Nittalla, 2017; Jesiek et al., 2018).

Especially relevant for this paper, we also coded for Technical work activities, or those involving technical expertise or tasks (e.g., calculations, analysis or modeling, design, working with CAD drawings, etc.). For the analysis presented here, we pulled all interview data coded as Technical from the 33 interview transcripts. We then sought to inductively identify instances where participants described social interactions or negotiations in completing a technical work assignment or task. In weekly meetings, our research team discussed the various kinds of interplay we saw between the social and technical dimensions of the coded examples. Through this iterative process, we identified three main themes. In the following section we present the most salient examples from our empirical data that illustrate on these themes, as well as discuss connections with other theories and studies.

Findings: Sociotechnical practices in engineering

Here we present examples of how technical expertise and social interactions are linked or combined in various kinds of workplace performances. We specifically focus on three types of sociotechnical practices in engineering: 1) learning in engineering practice, 2) engineers as sociotechnical gatekeepers and 3) sociotechnical interactions with boundary objects. For each theme, we also briefly discuss how our findings relate to the broader literature.

Learning in Engineering Practice

To complete technical tasks, engineers must often learn on the job. In our data, we identified two different types of learning: formal and informal. Formal learning happens during interventions that have been developed specifically to upskill engineers. For example, in Thomas’s co-op experience, he was assigned work related to lean manufacturing in a company that produced medical devices including “CT scanners, MRI machines, any of the imaging equipment that you’d see in the hospital for cancer detection.” However, Thomas recognized that he lacked experience in manufacturing:

> I actually haven’t had any coursework really related to lean manufacturing, besides what is taught in mechanical engineering [course]. I think there’s a little bit taught in [other courses] freshman year, but the broad concept of six sigma and lean is hinted at.

Fortunately, Thomas was able to sign up for a three-day boot camp to get all the basics he needed to complete his work:

> I mostly learned about lean manufacturing last summer. They have a boot camp that they put you through … [Parent Company] has a Center of Excellence for lean manufacturing, and they define all of the initiatives that manufacturing plants around the country should be following.

Thus, training in a “boot camp” is one example of formal learning in the workplace. However, our participants more often described instances of informal learning, that is, the learning that happens through experience and social interactions. For instance, this is how Nathan learned about Finite Element Analysis (FEA):
I worked with quite a few people, and one thing I really, really learned a lot about this term was finite element analysis, and that was just because all the components that I was designing had to be tested and verified. I probably came up with 20 different designs before we finally ended up settling with something.

In addition to learning FEA by testing various designs, Nathan also learned by interacting with experts on the job, who would informally teach him how to use the FEA software:

I didn’t know anything about that, so I met with – [my colleague] he was actually a PhD in finite element analysis, or I didn’t know what he was, he was the FEA guy there at [Healthcare Product Company] – a couple times, and he would teach me how to submit something to Abacus; they had a cluster you could submit projects to. I also met with some other engineers that taught me how to run FEAs locally on NX.

Therefore, Nathan learned FEA both by testing different prototypes and by engaging with senior colleagues, which could generally be classified as informal learning experiences.

In both cases, it is worth noting the dynamics of the technical and social dimensions of engineering work. Both engineers needed to complete technical tasks; applying lean manufacturing on one hand and running FEA tests on the other. Yet in order to complete such technical tasks, they had to engage with others to learn. This finding is aligned with other studies looking at how engineers learn in practice. For instance, Collin’s (2002) phenomenographic study of design engineers working in Finnish high-tech companies identified six categories of workplace learning: 1) “Learning through doing the job itself” (p. 141), 2) “Learning through Co-operation and Interaction with Colleagues” (p. 141), 3) “Learning through Evaluating Work Experiences” (p. 142), 4) “Learning through Taking Over Something New” (p. 144), 5) “Learning through Formal Education” (p. 146), and 6) “Learning from Contexts Outside Work” (p. 146).

Collin’s (2002) fifth category aligns clearly with the first example reported in this section, where learning happened through a formal development program. In contrast, our second example is a blend of Collin’s (2002) first and second categories, as our interviewee reported learning through interactions with two experienced colleagues, as well as by running FEA tests multiple times (that is, doing the job itself).

Engineers as Sociotechnical Gatekeepers

Technical work often requires navigating social relationships. Ramirez and Dickenson (2010), who investigated the labor associated with gaining knowledge outside organizations, explain that: “Given the importance ‘bridging’ functions play in gatekeeper roles, a greater understanding of the skills required for such a bridging role, for example, the balancing between communication and interpretive skills and “hard” technical knowledge in different national contexts, would be highly valuable” (p. 116). In the following examples, an understanding of the gatekeeper role in engineering contexts will be explored.

To begin, engineer might act as gatekeepers themselves and/or need to interact with a gatekeeper in order to do their work. For example, one participant, Eliza, described her role as a service engineer in gatekeeper terms. More specifically, Eliza has “all of that data for reliability,” and needs to provide and analyze this data for other people and operators in her company, as well as for customers and the FAA (Federal Aviation Administration). As the gatekeeper, Eliza gets requests such as: “I have this failure, can you track and tell me if we had this failure before? Is it I’m seeing a new thing or is this old?” She also often attends meetings so she can address “any issues that come up” that require consulting her data set. Here, Eliza is managing technical tasks such as analyzing data while navigating the social elements of responding to those who request her data and/or specific data analysis tasks.
As the engineer who oversees this data, Eliza also described needing to be available after hours. She can be contacted any hour of the day, with requests such as: “We sent you this stuff. Go work this case. Go into the OSD Tool and start looking it up.” When she is contacted, she is required to “work the issue.” As the keeper of the reliability data, Eliza must navigate working with numerous requests for quick analysis. She also reports needing to manage communication with stakeholders from diverse cultural backgrounds, which can require considerable consideration and sensitivity. For instance, Eliza explained how an issue could come from the customer and then passed through numerous people before she finally receives it. As she is “trying to figure out how to get the message back to the customer in the easiest way possible,” Eliza has to consider:

… not ignoring anyone, not keeping anyone out of the loop, and not hurting anyone’s feelings because there’s certain people who want the correspondence to go through them, like regional customer service managers, and they want everything you say to the customer ... You send everything to them and then, they send everything to the customer which seems to be redundant but that’s what they do, and it's okay.

While Eliza is the one with access to the reliability data, in some cases she also needs to call upon other people for approvals that she does not have the ability to give. As she explains:

For example, one of the things if something happens in the field and they noticed that there are some nicks on there, whatever, and they look up the maintenance manual and they say, “Oh, these nicks are not allowed. I need to go repair these. However, where I’m at right now, I don’t have the ability to repair them.”

In this case, Eliza describes needing to write a “technical variance” document to allow the operator to fly the plane somewhere else where it can be repaired. However, this document “needs to be signed by certain people,” so in this instance Eliza needs to contact another gatekeeper, even if it’s “4 am in the morning, you call the chief design engineer and say, ‘I'm sorry, [Ryan]. I need you to sign this.’”

In the examples described above, Eliza acts as both a gatekeeper of information and someone must contact other gatekeepers for certain approvals. When only particular people have the ability to do something, technical work becomes naturally intertwined with social aspects, such as needing to communicate and coordinate with other professionals to get a job done. Researchers have framed this type of activity as technical coordination (Trevelyan, 2007) where engineers work to get others’ “willing cooperation” as part of their job. However, in this case, Eliza acts as the gatekeeper who needs others’ willing cooperation, but also needs to be willing to cooperate with those who need information or assistance from her.

Another participant in our study, Ken, worked as an engineering intern at an automotive company and in this role had to navigate the social aspects of working with a gatekeeper. In his case, there was one “person that [has] full knowledge of hybrid vehicles. Anything that has to do with high voltage, you have to report to [Tessa].” Ken went on to explain that:

[Tessa] and [Daniel] are the only two people allowed to ever power up or power down a vehicle that has high voltage, which was a huge deal because she’s actually not an engineer, but she’s the only person that has any knowledge in this. It’s very concerning that actually a lot of the higher ups in your line didn’t know a lot of the procedures either. They just know report to [Tessa]. She’s the one that carries all the names on the ... You had to fill out a sign saying, “This is a high voltage area. If you have any emergencies, contact [Tessa].” She carries a lot of responsibility because anything that’s hybrid related falls under her.

Here, Ken explained how Tessa was the gatekeeper associated with anything related to high voltage and hybrid cars. Furthermore, Ken highlighted the fact that even more senior staff in
the company needed to go through Tessa. However, the fact that Tessa, as the gatekeeper, is the only one that knows a lot of the procedures seemed to slightly concern Ken.

In addition to describing Tessa as a gatekeeper, Ken mentioned two other characteristics about her. First, Ken mentions that "she [Tessa] used to be a he." Ken additionally describes how Tessa did not study engineering, but that "when she studied, initially she did design. Then she focused on the electrical design, I think." It is important to highlight that Ken brought up these two personal characteristics about Tessa in his interview: by mentioning Tessa's gender identity and education level as passing remarks, Ken is demonstrating that in carrying out his work he has learned about aspects of his colleague s' personal identities. This indicates that technical tasks often cannot be completed without a social component that may or may not impact the nature of the interaction. The attention to gender and sexual identities in the workplace is an area that demands further investigation. With gender issues pervasive in engineering, it would be valuable to understand how to train engineers to more sensitively navigate situations involving diverse identities and demographic characteristics.

In this case, Ken also describes that another aspect of this work included a cultural dimension. Most of the team, including Tessa and Daniel, were German. Ken explained that "Germans are very focused on one issue" while the "American side is more horizontal learning." These different ways of approaching work caused "a lot of disputes on that sort of thing because they both think completely different." Again, we see that Ken needed to navigate the technical aspects of his work while also managing the social dimensions.

In the examples above, Eliza and Ken were required to interact with gatekeepers to accomplish their work. In Eliza’s case, she also acted as a gatekeeper herself, needing to switch back and forth depending on the scenario. In both cases, Eliza and Ken recognized the importance of considering with whom they were interacting and then adjusting their behaviour based on the personal characteristics of their colleagues, emphasizing the inextricable link between the social and technical aspects of engineering practice.

**Sociotechnical interactions with boundary objects**

Our data – and the wider literature – suggests that engineering work often involves sociotechnical interactions with “boundary objects,” defined by Hawkins and Rezazade M. as “a physical, abstract, or mental object that serves as a focal point in collaboration enabling parties to represent, transform and share knowledge” (2012, p. 1805). Here we present two related examples from our interview with Albert, a chemical engineer in his second year of full-time work at a pharmaceutical company. The first involves Albert’s project management work overseeing installation of a distillation column, which in turn involves extensive use of a Piping and Instrumentation Diagram (P&ID). As Albert describes this important document:

> One of the really important things was to make sure that, because everyone was coming from a different perspective, make sure that we’re all talking about the same things and speaking the same language, so to say. I think one of the main tools for that was to have the P&ID [piping and instrumentation diagram] out and showing specific names of instruments or parts of that system, … everyone sitting at the table could call it out and it had a picture in front of us to make sure that we’re all talking about the same thing.

As this passage suggests, the P&ID served as a boundary object in the team’s meetings. Reading the diagram surely requires technical skill – developed formally or informally. But just as importantly, it provided the team with a physical representation that helps them span knowledge boundaries stemming from their different backgrounds, expertise, and terminology preferences. Indeed, Albert discusses elsewhere how these meetings involved a reasonably diverse cast of characters, including another project manager, process engineers, the head of project engineering, and an operations specialist from the plant. Albert’s depiction of these exchanges thus highlights how information is translated and
transformed to establish shared meaning and understanding through sociotechnical interactions among a diverse work team.

This example also resonates with the work of Bucciarelli, whose idea of “object worlds” describes how technical professionals see objects differently based on their “different competencies, skills, responsibilities and interests” (2002, p. 224). Further, he points to the significance of engineering drawings as “linguistic artifacts(elements) in design negotiations”, adding that these “artifacts also serve an essential function beyond object worlds: they enable negotiations among participants with different responsibilities and technical interests” (p. 230). The P&ID diagram is thus a sociotechnical boundary object \textit{par excellence}.

A second example of sociotechnical interactions with a very different kind of boundary object can be found in another situation described by Albert, one in which the highly indeterminate nature of equipment in the plant becomes evident in the transition from installation and startup to the full-scale operation of a different production line. As Albert explains, “there is [sic] always things that come from operations at a point later in time when you have more time to think about it, or if you physically see what’s coming in place.” He more specifically recounts equipment problems raised by the operators in one of the buildings he supports, namely: “one, that it is hard, physically challenging, to replace the filters in that line, which has to be done whenever the line is plugged. Two, the fact that the filters what they feel like are plugging too frequently.” Albert in turn describes actions he took and questions he asked once he was aware of possible problems, e.g., “Is this urgent?”, “What is the trigger or reason behind this request?”, “How long has this been going on?”, “Is this an immediate safety issue?”, “What kind of resources do we need?”, and “What do you think is the best way forward?” Here Albert shifts into problem definition mode, trying to “fully understand the problem” through interactions with equipment, operators, and other stakeholders.

While Albert’s focus is on one boundary object (the filters), he must simultaneously consider and address two partially distinct technical concerns. Regarding the question of whether the filters are too difficult to replace, he describes how he asked an operator to show him the problem, ultimately concluding: “It’s not necessarily unsafe, but it is an ergonomic issue.” He then describes how this initial assessment helped him prioritize this particular issue in relation to other work tasks, and also set the stage for triage efforts with other stakeholders (such as a plant specialist) to confirm his assessment and explore possible solutions. As Albert explains, subsequent discussions and meetings confirmed that moving the filters was feasible to implement would probably also address the underlying ergonomic problem.

Albert describes the second problem as more challenging, both from a technical and social perspective. His process begins with trying to “fully understand what is the system” and asking questions like “why are we filtering it, are we expecting corrosion, … [and] why is it plugging?” He describes bringing together a team to answer these questions and consider solutions such as relaxing the filter specifications, while at the same time being mindful of related consequences such as degrading the system performance downstream from the filters. Albert in turn describes how the team ultimately settles on using a different type of filter after making sure the building manager and others are all on board – what Trevelyan refers to as gaining “willing cooperation” (2007, p. 191). This change is next formally tracked and approved through a “change control” process, then implemented by maintenance staff.

Reflecting on this case, there are few if any parts of this story that are purely technical in nature. For instance, Albert’s initial evaluation of the filter location seems to rely heavily on his own professional judgments about ergonomics and workplace safety, but even this requires direct engagement with the operators, followed by a highly collaborative process to review and implement the proposed changes. Even if Albert or others were to undertake solitary tasks like system simulation or analysis (e.g., to evaluate how changing the filter specifications might impact overall system performance), the results will feed into a “distributed cognition” process as inputs and expertise from multiple actors enables collaborative selection and implementation of a preferred (and hopefully effective) solution.

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This point is consistent with Jonassen, Strobel, and Lee’s (2006) studies of engineering practice which lead them to argue that “[engineering] problem solving knowledge is distributed among team members” (p. 144), and that “even in small companies … engineers nearly always rely on others’ knowledge in order to solve problems” (p. 144).

Another point worth noting is the considerable indeterminacy that characterizes technical objects and systems as they become operational, including as human actors work with those systems in diverse ways (e.g., to operate and maintain, monitor performance, etc.). In the case presented here, two unexpected problems surfaced as human operators interacted with the filters, one ergonomic in nature and the other related to the technical performance of the equipment. Other case studies have described similar dynamics with other kinds of engineering projects, such as Bovy and Vinck’s analysis of city engineers developing a system for collecting household waste, including through the design of new waste containers (2003). As they underscore, once a given object or system enters into use it may reveal the “heterogeneity of society” (e.g., citizens using waste bins in unexpected ways, or equipment operators unhappy about the ergonomics of filter replacement), and conversely the “unexpected characteristics” of objects (e.g., waste containers that prove difficult to modify in response to changing needs, or filters plugging up much too quickly) (p. 53).

With the benefit of hindsight, it might also be tempting to argue that there were obvious and objectively correct solutions to the two problems described by Albert. Yet as actor-network theory asserts, we should be careful not to confuse our causalities (Bovy & Vinck, 2003, p. 75). One could argue that certain pathways for problem definition or solution are relatively more probable in a given situation or set of circumstances, but complete determinism is impossible, in no small part due to the complex sociotechnical dynamics that are in play.

Discussion and Conclusion

In this paper, we presented three kinds of sociotechnical activities experienced by early career engineering professionals, provide preliminary insights towards the development of a typology of the sociotechnical engineering practice. We believe this work could inform engineering education by emphasizing the inherently sociotechnical nature of engineering. In light of the findings, we further challenge readers to consider: What might engineering education look like if designed around the idea that engineering practice is predominantly sociotechnical? To be sure, engineering students do have experiences that resemble some of the situations described above, such as when they engage in informal teaching and learning interactions with their peers; act as gatekeepers over data, devices, or systems; or seek to influence other gatekeepers who control access to things they need, such as a specific data set, test rig, or lab supplies. Yet rarely are such experiences accompanied by intentional mentoring and structured reflection to help students see how the social and technical dimensions of practice are intertwined. Engineering students also frequently interact with boundary objects during their studies, including technical drawings and diagrams, laboratory equipment, and physical prototypes, to name a few. Yet such objects are often presented in abstract or idealized forms, without a sense for the dense networks of connections and negotiations of meaning frequently associated with them.

As we and others have suggested, problem- and project-based learning (PBL) approaches can help immerse students in learning environments that reflect some of the sociotechnical realities of practice, including by having them grapple with realistic and authentic problems, work on diverse teams, and learn technical concepts on-demand and within context (Sheppard et al., 2009). Yet the breadth, depth, and quality of PBL implementation within the U.S. remain spotty, often appearing in the first and last – but not middle – years of the typical engineering curriculum (Sheppard et al., 2009). Other scholars have drawn inspiration from the field of science and technology studies (STS) to develop introductory coursework that explicitly frames “engineering as a socio-technical process” and “technology as a socio-technical system” (e.g., see Cohen et al., 2014, p. 12). New directions such as integrating social justice into core engineering curricula are also emerging (Johnson et al., 2016;
Leydens & Lucena, 2017). Nonetheless, such approaches remain relatively limited in U.S. engineering programs. Another promising approach involves using reflection activities to scaffold learning during internship or co-op experiences, giving students rich opportunities to experience and observe practice more directly (Jesiek, Trellinger, Nittala, & Campbell, 2017). Yet not all students take such positions, and few programs make use of such scaffolds for learning and development.

It is challenging to revise our approaches to engineering education without tools and strategies that help us conceptualize ways to bring a sociotechnical framing into the core of the engineering curriculum. Our future work includes continuing efforts to develop a typology of engineering practice through the iterative process of re-reading and coding our data. With expanded findings and a typology in place, we imagine enhancing engineering education pedagogies to include more experiences and practices that are explicitly sociotechnical.

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National, disciplinary and institutional influences on curriculum:
A preliminary exploration across two Washington Accord countries

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Abstract - The Washington Accord signifies a level of conformity in graduate outcomes in bachelors’ programs in engineering in member countries. However, the same level of conformity is not assumed or required in the details of how curricula are compiled and executed in particular institutions. These details have a significant influence on students’ trajectories through these degrees, in particular on academic success as it relates to the transition from school and family background. This article, part of a broader study looking at the influence of curriculum on student learning, seeks to develop ways to understand differences in curricular arrangements. To this end, it considers two institutions in each of two Washington Accord signatory countries and focuses on the first year of the chemical engineering bachelors’ programs. The analysis considers both the breakdown across particular courses, as well as the overall contact hours per semester. A preliminary examination of these data shows differences not only across but also within each country. These are discussed in the context of choices that are available for curriculum designers in engineering, especially in the context of the first-year experience.

Introduction

Curriculum continues to be an important topic of debate in engineering education, with concerns about what graduates can and should do often being related back to whether the curriculum is serving its purpose or not. Over the last two decades, there have been substantial moves to global systems of equivalence, notably through the Washington Accord, and the Bologna system, both of which base accreditation decisions on assessment of outcomes (Case 2011, 2017). However, individual institutions and countries still have considerable latitude in structuring their curriculum at a more detailed level. These differences are not well studied at a comparative level, and we know little about how different curricular arrangements relate to the detailed development of student outcomes. Additionally, while much work has been done on students’ readiness for their intended professions, there is still much to know about how specific
institutional curricula are designed, as well as how the context in which it exists influences how knowledge is acquired by students and how it shapes their ways of thinking.

The purpose of the larger study from which this paper is drawn is to investigate the design of curricula in selected first-year engineering programmes with the goal of highlighting how different institutional, disciplinary, and societal contexts shape how knowledge is recontextualized and acquired by students. Specifically, the project will explore the design of curricula across two different countries to determine how differences in approach to pedagogy and what counts as knowledge interface with the development of individual student identities. While the aim of the larger project is to understand knowledge recontextualization and identity formation, this particular paper only focuses on a very descriptive documentation of the institutional contexts.

In the following sections, we provide an overview of the study’s theoretical orientation as well as a discussion of the design of the broader study from which this work is drawn. Later we share some results from our context documentation, primarily the key similarities and differences across institutions and programs as well as some results from student interviews drawn from their overall course experience. The paper concludes with key discussions about the implications of our findings as well as current and future research activities.

The study

Theoretical orientation

This study takes a departure point from the position that was laid out by Case et al. (2016) in their comparative study of undergraduate curricular arrangements in three African countries which looked at curricula in the context not only of their histories but in the contemporary context especially of external drivers and internal resources that have impact on the directions for curriculum reform. Notwithstanding the significant moves towards global ‘harmonization’ and mutual accreditation, different national contexts and histories are important influences on curriculum.

There are many different approaches to researching curriculum, and for the purposes of our study which is interested in the influence of the local context, we thus look to explain the significant differences that are observed in different national and institutional contexts. This study is situated in reference to the significant struggle involving multiple stakeholders with different views on what should be prioritized and legitimated as knowledge (Young and Muller 2014). Engineering has a location which means that it has stakeholders both inside and outside the university that have different views on what should be prioritized. Curriculum thus involves a recontextualization of disciplinary/professional knowledge, and for engineering, this reflects an ongoing tension between theoretical and practical orientations to the profession. This theoretical approach to researching engineering curriculum is proving of significant value in the field, and here we are also informed by the work by Smit (2017), Wolmarans (2018), and Wolff (2017).

The present paper reports on a very preliminary descriptive scoping out of curriculum and context; it is acknowledged that further work will be needed to identify influences and relationships.
Research Design

This study employs a longitudinal, comparative approach to studying the impact of context on curriculum. This paper is drawn from a much larger study that follows the progression of chemical engineering and chemistry/biochemistry students across the four years of their degree completion in two universities across three countries namely: South Africa, United Kingdom and the United States of America.

For the purposes of the present paper, we focus only on the first year of the chemical engineering curriculum, and on the South African and US universities. We chose these because they are both four-year degrees which students enter after 12 years of schooling, and thus in some regard, one would anticipate a degree of comparability of the first-year curricula. Our broader study is also interested in the transformative possibilities of higher education in the context of increasingly diverse student populations, and for this reason these two countries offer potentially useful locations for investigation. Therefore, our overview of the institutions, which follows, will specifically focus on the racial composition of the student body at each institution.

Context of Universities

In this section, we offer a short overview of the key features of each university in the study to allow for contextualization of the results.

University 1 (South Africa)
University 1 (U1) is a public research-intensive university and is highly ranked in the country as well as on the continent and internationally. In 2016, approximately 30,000 undergraduate students are registered at the university. About 5000 of these students are international students and come from 112 different countries.

University 2 (South Africa)
University 2 (U2) is also amongst South Africa’s leading public research-intensive institutions and also offers a comprehensive suite of programmes. The university also has around 30,000 undergraduate students. Besides the presence of a large number of international students, both U1 and U2 attract students from different racial backgrounds, as illustrated in Table 1.

<table>
<thead>
<tr>
<th>Group</th>
<th>U1</th>
<th>U2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total student enrollment (including PG)</td>
<td>28,703</td>
<td>31,639</td>
</tr>
<tr>
<td>Coloured</td>
<td>3,814</td>
<td>5,757</td>
</tr>
<tr>
<td>Black African</td>
<td>7,108</td>
<td>6,375</td>
</tr>
<tr>
<td>Indian/Asian</td>
<td>1,881</td>
<td>953</td>
</tr>
<tr>
<td>White</td>
<td>7,171</td>
<td>18,447</td>
</tr>
<tr>
<td>International</td>
<td>4,914</td>
<td>included in above</td>
</tr>
</tbody>
</table>

Table 1. SA institutions student enrollment comparisons (2017 data)
University 3 (USA)

University 3 (U3) is a public land-grant research-intensive engineering focused institution. Land-grant institutions in the USA are mandated to provide educational opportunities whereby students can translate knowledge to practice, engaging in technological leadership and contribute to economic growth and global competitiveness within its home state and nationally as well. U3 is the third largest in its home state and enrolls 27,758 undergraduate students across 150 undergraduate degree programs. This number includes 1878 international students from 44 countries. The university also reports a 56.6 % male (n=15754) and 43.4% female (n=11938) split, non-reported is 66.

University 4 (USA)

University 4 (U4) is a public space-grant research-intensive institution. Space-grant institutions maintain robust research programs and educational activities aimed at advancing research related in the field of aeronautics and outer space. As a member of the conglomerate of institutions in its home state, U4 has the fourth largest enrolment of the group. In 2018, the university reported a total enrolment of 11,260 undergraduate students across 111 undergraduate degree programs. This number includes 197 international students from 38 countries. The university reports 55% male (n=6,193) and 45% female (n=5,067) split. U4 also has an almost 50% enrolment of ethnic and racial minorities. Table 2 summarises the total undergraduate enrollment and racial/ethnic breakdown for the two US institutions:

### Table 2. US institutions student undergraduate enrollment comparisons

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<thead>
<tr>
<th>Group</th>
<th>U3 Fall 2018 enrolment</th>
<th>U4 Fall 2018 enrolment</th>
</tr>
</thead>
<tbody>
<tr>
<td>American Indian or Alaskan Native</td>
<td>34</td>
<td>12</td>
</tr>
<tr>
<td>Asian</td>
<td>2738</td>
<td>1477</td>
</tr>
<tr>
<td>Black or African American</td>
<td>1169</td>
<td>2864</td>
</tr>
<tr>
<td>Hispanics of any race</td>
<td>1789</td>
<td>879</td>
</tr>
<tr>
<td>Native Hawaiian or Pacific Islander</td>
<td>31</td>
<td>8</td>
</tr>
<tr>
<td>Nonresident Alien (International)</td>
<td>1878</td>
<td>1197</td>
</tr>
<tr>
<td>Not reported</td>
<td>705</td>
<td>315</td>
</tr>
<tr>
<td>Two or more races</td>
<td>1333</td>
<td>-</td>
</tr>
</tbody>
</table>
Data collection and analysis

The broader study involves data in the form of student interviews, faculty interviews, course and curriculum documents, and classroom recordings. In this paper, we share the results garnered from chemical engineering curriculum documents such as course schedules and contact time information. We also draw on representative interview data which give some indication of students’ perception of their course experience in each country and university.

Results

In this section, we present an overview of the engineering programs at each institution with a breakdown of courses to highlight the variance in each context. We also provide a comparison of contact hours, meaning the amount of time students are expected to be in classes. Finally, we share some students’ reflections on the curriculum.

Overview of engineering programs

In three of the study institutions, students take a general engineering first-year program, where all engineering students must enroll in a collation of courses that are compulsory after which they will specialize in their second year in courses associated with their chosen majors. The core courses in such programs thus usually involve general engineering courses as well as mathematics, chemistry, and physics along with other university determined electives which often include academic writing or communication courses. In one institution, U1, students take a first-year program that is directly linked to their major (chemical engineering).

Course breakdown

Table 3 summarises the percentage of time students spend in particular courses in their first year. This was determined by documenting the courses required in the first year and assigning them subject categories, as shown in the headings of Table 3, based on the number of credit hours associated with each course. As can be seen, there are similarities in the overall types of courses across all universities and programs. While U1 is the only institution that has a formal first-year chemical engineering course, the breakdown of time spent in other courses is fairly comparable to all other programs for most subject areas. The variety of time spent on course such as Mathematics, Chemistry, and Physics is highlighted. The largest disparity exists for U2’s allotment for physics, general engineering, and professional communication, which is much smaller for physics and professional communication while significantly more for general engineering.
Table 3 – Summary of course breakdown across programs

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>25%</td>
<td>25%</td>
<td>12%</td>
<td>30%</td>
<td>8%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>U2</td>
<td>20%</td>
<td>20%</td>
<td>14%</td>
<td>5%</td>
<td>-</td>
<td>36%</td>
<td>5%</td>
<td></td>
</tr>
<tr>
<td>U3</td>
<td>15%</td>
<td>24%</td>
<td>12%</td>
<td></td>
<td>18%</td>
<td>18%</td>
<td>12%</td>
<td></td>
</tr>
<tr>
<td>U4</td>
<td>24%</td>
<td>29%</td>
<td>12%</td>
<td></td>
<td>18%</td>
<td></td>
<td>18%</td>
<td></td>
</tr>
</tbody>
</table>

Contact hours

We present here a breakdown of typical contact hours for the semester. By contact hours we mean the amount of time spent in a scheduled formal classroom setting that encompasses lectures, labs, and recitations/tutorial sessions. Table 4 illustrates there is substantial national uniformity in this regard. However, there are significant differences across the countries. The South African institutions, U1 and U2, especially U2 spend significantly more time teaching which can be seen by the fairly wide gap shown by the hours per week and semester total in the table.

Table 4 – Summary of contact hours across institutions

<table>
<thead>
<tr>
<th>University</th>
<th>Lecture hours per week</th>
<th>Practical hours per week</th>
<th>Tutorial hours per week</th>
<th>Total hours per week</th>
<th>Teaching weeks per academic year</th>
<th>Hours per academic year</th>
</tr>
</thead>
<tbody>
<tr>
<td>U1</td>
<td>20</td>
<td>6</td>
<td>5</td>
<td>31</td>
<td>24</td>
<td>744</td>
</tr>
<tr>
<td>U2</td>
<td>18</td>
<td>5</td>
<td>9</td>
<td>32</td>
<td>26</td>
<td>832</td>
</tr>
<tr>
<td>U3</td>
<td>15</td>
<td>2</td>
<td>2</td>
<td>19</td>
<td>30</td>
<td>570</td>
</tr>
<tr>
<td>U4</td>
<td>12</td>
<td>2</td>
<td>3</td>
<td>17</td>
<td>30</td>
<td>510</td>
</tr>
</tbody>
</table>

The data in the table below were determined using the number of contact hours associated with each course in the categories of lectures, practicals, and tutorials. These hours were then totaled across a typical week and then multiplied by the number of teaching weeks in the academic year. The total number of hours represent how many hours are spent in an academic year in in-class settings. While the lecture time across countries is comparable, with the exception of U3, there is considerably more time spent in practical classes and tutorials in South Africa than in the United States. It is notable that the South African students have more contact hours per semester, but also because the semesters are shorter, they have significantly more contact hours in each week of the semester.
Student reflections on the curriculum

In addition to documenting the curricular structure and contact hours, we also captured how students experienced their respective curricula. To this end, one of the interview questions asked students to explain what a typical week or day of study looked like for them. In looking at their responses, and noting the curriculum differences outlined above, it is not surprising that the South African students described quite different experiences to the US students. At the same time, we were looked more closely at the detail of these data, especially regarding how students make choices on how to spend their time.

Since we are at a preliminary stage in this analysis and given the scope in this paper, here we have chosen to show representative quotes from students in each institution that give some detail on how national differences in curriculum structure impact on the student learning experience. In the student excerpts, we have highlighted comments that show a marked difference in how the SA students spend their time compared to the US students.

We begin this section with three sample quotes from South African students. These quotes show further evidence that they have contact time during nearly all available work hours in the weekdays, from 8/9 am till 5 pm, with a break over lunch. They talk about the difficulty of managing to study in weekday evenings for the necessary class assignments.

Okay. So, my timetable, in fact... Okay so, from nine, I start my lectures from nine, ten, 11, 12 up until 1 pm. And then from 1 pm to two, that's when I take my lunch and then from two to four or five, that's the time where I go to tutorial sessions. And from then I will start after my tutorial and then it's 6 pm, I will have my dinner and then after that, I will study again. – UNI-4-CE10, U1

Mondays, we finish lectures... We start lectures at nine and we finish them at one. And then we have the afternoon off, but we normally have quite a bit of work to do, so I normally work in the libraries after, till five or so, and then go back. This week has been very busy because we have a Maths test, so then I normally work till five at the campus and then work again in the evenings, till ten, and, basically, every day. And then on the weekends, I take time off. – UNI-4-CE3, U1

Well, very, very busy.... well I mainly have class from about 8 until 1, 8-12, 8-1, and then I have a tutorial every afternoon from 2 until 4.30 or 5 o'clock and that's my class day. Then I go back to res, try and relax for about half an hour and then start on preparations for the next day's tutorial. This past week I have trying to squeeze test week preparations, but it hasn't really been so successful [laugh]... but ja, I feel during the semester, my days revolve around academics and weekends I try and relax… We go to class from 8 and then the majority of the time we end either at 5 or 4 and studying is obviously a mission because there are so many hours in the day and when you bet home you are very tired and all of that, but it is nice to take a nap before you start studying and ja, most of the time I don’t have time for anything else, but studying but I feel, if you are an Engineering student, you don’t really have a life outside of these four walls. - UNI-3-CE1, U2

1 The codes refer to the student in a particular program at a particular university
The quotes from the South African institutions indicate that students spend a significant amount of time in an actual in-class setting which aligns with the contact hours description presented earlier in Table 4. Students in both regions discuss taking time off on the weekends however, the South African students stress not being able to engage in much else other than academics during the weekdays.

On the flip side, the US students’ description of their weekly schedules demonstrates their ability to engage in other external university activities such as reviewing course materials at their own convenience, working out or participating in sports-related activities as a part of their daily routine. Below we present sample quotes from US students. Their descriptions of their weeks are very different, with particular course commitments on particularly days, but usually with plans on how to use the remaining time during these weekday daytime hours.

Okay, so I have 8 am’s every single day. A lot of people dissuade them as awful, but I think they're good because you get up, you sleep through class a little bit but at the end of the day, I found that the class doesn't help a ton. I figured it's a lot you gotta go back and teach yourself anyways. So, you force yourself to get up, get through class, kind of somewhat understand it and then you have the entire day to work with yourself. So, I'll have class starting at 8, I'll work out right afterwards, I'll have Chem class from 2:30-3:45, followed by Physics 2306 4-5:15 on Monday. Tuesday will be 8-9:15 engineering followed by humanities class I have to take to get a CLE out of the way and then I'll have Physics lab from 12:10 to 2:10 and I'll work out afterwards too. Working out definitely keeps me sane, reduces a lot of stress. – Elliot, U3

So, on Monday's, it's my schedule of going to math discussion, physics, then I have math lecture, then I go to chem and then after that, I usually have my chem tutorial center. Monday's consist of me going to the rec to exercise a little bit and then I'll come back, do my homework with my study groups. Tuesday's, in the morning I go to my lab that I'm a part of. So, I'm a part of Doctor XYZ's lab on campus. So, I go to that from around most of the morning til noon. Then after that I usually have biology lecture and then from there, I have most of the day off and I usually have an intramural basketball game and then I usually do my homework, as well. Wednesday's are probably my worst day. I'm in class from 8 am til 8:30 pm. So, it's basically every class. My physics, my math, I do chem as well. Then my chem lab and yeah, so that's probably the most tiring day. Other than that, that day's just class and then I do my homework and go to sleep. – Taylor, U4

Discussion and conclusions

We set out in this paper to do preliminary work comparing first-year curricula in an engineering program across four institutions, two in the USA and two in South Africa. Our interest for the purposes of the broader study is to see how curricula relate to local contexts, even though they are now linked in global systems of mutual accreditation (the Washington Accord in the case of these two countries). Our theoretical position on curriculum is that it will likely reflect the context in that the different configuration of state, industry and academic players will be very specific to the national setting. We were also interested to note difference within a country across institutions with different histories and missions.

The South African institutions are similar in terms of overall undergraduate enrollments and in engineering enrollments specifically. The US institutions are very different in this regard, with
U3 have overall larger enrollment as well as engineering forming a much larger proportion of these enrollments. U4 is the smallest institution in this group, both in terms of overall enrollments and also in terms of engineering enrollments.

The paper also considered racial demographics across the institutions, showing quite some variation across the two institutions in each country. Here, U2 and U3 have the largest proportion of white students in the sample. All institutions have stated commitments to furthering diversity and inclusion in their student body. However, the numbers still show the lack of equal representation between males and females enrolled in engineering departments. Currently, U1 reports 29% of students enrolled in their engineering program are females while U2 has approximately 25%. In the US, U3 reports 21% while U3 has 22%. Interestingly, these numbers are fairly consistent across institutions and contexts and could prove to be a promising area of future research investigation.

Our study performed two quantitative analyses of the first-year curricula. Firstly, we considered the credit breakdown across different subject years in the first year. There is a substantial difference in each institution, but overall it can be noted that the US students, as is already anecdotally known, have a wider spread of subjects as well as more elective choice in their first year. This can be related to the general principle of general education which informs undergraduate curricula in that country.

Our second quantitative analysis is more compelling, showing substantial changes in the allocation of contact hours in the first year of the engineering curriculum. South African engineering students have lectures, tutorials and practicals totaling around 30 hours in the week, meaning they spend most mornings back to back in lectures, with tutorials and practicals on nearly all afternoons. US engineering students only have just over half of these contact hours.

The study provided preliminary evidence on how these different curricula are reflected in students’ accounts of their experiences. We focused here on the contact hours since that provided the starkest contrast. What we do note is South African students reporting more exhaustion throughout the day and difficulty in having to study in weekday evenings after these full days. US students have accounts of their weekday activities which are more deliberate in how they balance self-study as well as extracurricular activities. However, students’ experiences of relatively higher contact hours in South African universities should also be seen in light of the fact that the semester length in South African universities is smaller than in their US counterparts (12 in South Africa vs. 15 in the US). The reduced semester length further adds to more contact hours per week to ensure that the curricular requirements are met. Additionally, it should be noted that students in the US have the option to complete Advanced Placement (AP) credit courses during high school, which substitute for introductory courses during the initial years of the university. The AP credits that the US students carry further reduces their contact hours.

These exploratory findings will form the basis for further investigations in the broader study. This paper has at least demonstrated that there is substantial variation in the details of how engineering curricula are arranged not only across countries but within countries and that this has a notable influence on students’ learning experiences.
References


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First year engineering students’ perceptions of the purposes of classroom assessment

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Abstract: Given the importance of assessment in improving student learning and teaching practices, this paper explores how first year chemical engineering students describe the purposes of classroom assessment such as tests, quizzes, homework, project work, and lab work that they are assigned in their courses. Interview data were collected from 30 first year chemical engineering students at two US universities. A qualitative analysis of data was done to capture the themes emerging from the data. Results of the data analysis suggest that a majority of participants saw the classroom assessment as a means to engage in a procedural approach to learning. Additionally, several perceived classroom assessments as a measure of their learning, and an extrinsic motivation for studying and learning. These findings suggest that course instructors should design classroom assessment in ways that foster deep learning approaches and holistically measure all course learning outcomes.

Introduction

Assessment is widely accepted within the engineering and higher education community as a key aspect of teaching and learning. Assessment is a vital tool for understanding and documenting student learning, and improving teaching and learning practices. Much of teaching and learning rests on an assumption that students have a sense of the purpose of assessment activities similar to that defined by the instructor. However, research (e.g., Carless, 2006; MacLellan, 2001) suggests that this assumption is not always true. Hence, it is useful to find out how students perceive the purposes of classroom assessment so that effective steps can be taken to align students’ expectations of assessment and the assessment practices. To this end, this paper explores how first year engineering students describe the purposes of classroom assessment they are assigned in their courses.

Literature review

Purposes of assessment

In the context of engineering education, Rompelman (2000) notes the purpose of assessment as providing feedback on student attainment of learning objectives, which can then be used to modify the teaching and learning practices including the assessment processes, the activities of teachers and students, and the learning objectives. Classroom assessment has been categorized into three types based on the purpose it aims to achieve: assessment of learning, assessment for learning, and assessment as learning (Earl, 2013).

Assessment of learning, or summative assessment, is done to document student learning. It helps to determine how much students have learned, which in turn helps in the process of
selection and certification. Additionally, this form of assessment is used as a metric for institutional accountability and quality of teaching and learning. If the course of the module for which summative assessment was done is repeated, the results of summative assessment are used to improve the curriculum including the learning objectives, and the teaching and learning methods (Crawley, Malmqvist, Östlund, Brodeur, & Edström, 2014; Earl, 2013).

Assessment for learning, or formative assessment, is aimed at helping instructors and students improving teaching and learning practices. It provides information about how much students have learned which allows both teachers and students to adjust the teaching and learning practices used. Formative assessment is done when the students are in the process of learning and the results of formative assessment are used to provide feedback in terms of pace of instruction, topics of instruction, methods of instruction, and learning methods adopted by students (Crawley et al., 2014; Earl, 2013).

Finally, assessment as learning can be viewed in two different but related ways. First, students learn when they engage in assessment tasks such as completing assignments or revising for a test or an exam. Second, assessment as learning is also geared towards developing and using students’ metacognitive skills for their own learning. As students engage in the process of completing assignments or preparing for tests and exams, they engage in various metacognitive activities such as making sense of the new information, connecting it to their prior knowledge, and self-assessment of their learning. All these activities help students better learn the course material (Bloxham & Boyd, 2007; Earl, 2013). In the context of engineering, this often involves students practising solving set problems. Case & Marshall (2004) showed how this activity can be described as a ‘procedural approach to learning’ which can either be directed towards understanding the material (linked to a deep approach to learning) or learning techniques to pass examinations (linked to a surface approach to learning).

Student perceptions of assessment

While the importance of assessment for documenting and enhancing student learning in higher education in general and engineering in particular has been well established (see Crawley et al., 2014; Rompelman, 2000; Suskie, 2008), few studies have captured how students perceive the purpose of assessment. Instead, the scholarship on assessment in engineering education has mostly focused on two aspects: 1) development of different assessment methods and their influence on student learning (e.g., Bailey & Szabo, 2006; Burian, 2014; Nirmalakhandan, Daniel, & White, 2004), and 2) student experiences with different modes of assessment (e.g., Fernandes, Flores, & Lima, 2012). There has been, in general, a lack of research on how students perceive the purpose of assessment.

Students may not always have the same view of assessment’s purpose as has been described by the educational literature. For example, in a quantitative study conducted by MacLellan (2001), the author found that 82% of the student participants reported that assessment was “frequently” used to assign a grade or rank students. While more than half of the student respondents also noted that assessment was also done to motivate learning, diagnose strengths or weakness, and evaluate teaching, these purposes were only achieved “sometimes.” The same study also suggests that there is a difference in teacher and student conceptions of the purpose of assessment. In this study, most teachers noted that assessment is also frequently done to motivate learning and diagnose strengths and weaknesses in addition to grading student learning. Since assessment is generally designed by teachers who have a different conception of assessment’s purpose that the students for whom it is designed, it can be argued that this misalignment can lead to classroom assessment activities missing the mark in promoting student learning. Biggs (2003) advocates for constructive alignment in the design of teaching, which refers to an alignment between the course learning outcomes, assessment activities, and getting students to engage in appropriate learning activities that lead to student learning of the course.
outcomes. A lack of alignment between student and teacher perceptions of assessment may lead to students thinking of the classroom assessment that they are assigned as inappropriate, which may lead them to be disconnected from the learning activities and adopt a surface approach to learning (Struyven, Dochy, & Janssens, 2005). Hence, it is important to study how students experience the purpose of classroom assessment. By focusing on how students perceive assessment, more effective assessment practices can be designed to better cater to students’ needs, and misconceptions, if any, about assessment practices can be addressed. To this end, this study addresses the following research question: How do first year chemical engineering students describe the purposes of classroom assessment that they are assigned in their courses?

Methods

Participants for the study

To address the research question, we collected data in the form of semi-structured interviews from 30 first year chemical engineering students at two different universities (U1 & U2) in the USA. Half of the participants (U1CHE1 through U1CHE15) were from U1 and the other half (U2CHE1 through U2CHE15) were recruited from U2. We chose to collect data at two universities to increase the variation in the participant pool. By selecting students from two different institutional contexts, we sought to increase the transferability of the findings to different institutional contexts (Merriam, 1995). Variation in the participation pool was also present in terms of participants’ characteristics such as race (participants from various racial groups including White, Black, Asian, South Asian, and Latinx) and gender (14 male and 16 female participants). The decision to study chemical engineering students is guided by scholarship (e.g., Agrawal et al., 2018; Godfrey, 2014) that challenges the idea of engineering being monolithic thus highlighting the need for conducting research that explores student experiences at the level of engineering sub-disciplines.

Participants were recruited through a combination of electronic advertisement and in-person recruitment. The electronic advertisement was done through an email sent to first year chemical engineering students at both the institutions. Note that institution U1 admits first year engineering students into a general engineering program and students can declare their engineering major only at the end of the first year. So, for institution U1, we emailed students who had intended to choose chemical engineering as their major during admission. To enhance recruitment efforts, two members of the research team (Authors 1 & 2) also visited classes taken by first year engineering students to advertise the study.

Data collection and analysis

Data were collected in the form of semi-structured interviews as part of a larger study aimed to capture undergraduate students’ engagement with curricular knowledge in two different STEM disciplines (Pitterson, Case, Agrawal, & Hasbun, 2018). This paper focuses on the data collected from chemical engineering students in which they were asked to articulate the purpose of classroom assessment tasks such as tests, exams, quizzes, lab work, and project reports that they are required to complete. Probes were added to solicit details on how the different components of assessment helped achieve the various purposes noted by students.

The interviews were transcribed using professional transcription services for analysis. The analysis was informed by the literature on the purposes of assessment reviewed above, but codes were generated based on the data in a grounded fashion. The initial round of coding was done by Author 1. To improve trustworthiness of the findings, the initial set of codes were modified following a discussion with Authors 2 and 3. The following section discusses the results of the data analysis.
Results

Table 1 lists the final set of codes that were found in the data along with their definitions and the number of interviews in which the code appeared. It should be noted that each code represents a distinct theme that emerged from the data. As listed in Table 1, students’ perceptions of the purposes of assessment could be categorized into four categories: measure of learning, feedback on learning, means to procedural approach to learning, and extrinsic motivation for studying and learning. The following sections discuss these themes in detail with representative quotes.

<table>
<thead>
<tr>
<th>Code</th>
<th>Number of interviews with the code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Measure of learning</td>
<td>15</td>
<td>Student notes that assessment measures what they have learned in the course</td>
</tr>
<tr>
<td>Feedback on learning</td>
<td>2</td>
<td>Student notes that assessment provides them feedback on their learning of the course content and which areas require more attention from them</td>
</tr>
<tr>
<td>Means to procedural approach to learning</td>
<td>21</td>
<td>Student notes that assessment tasks provide them with a means to engage in procedural approach to learning</td>
</tr>
<tr>
<td>Extrinsic motivation for studying and learning</td>
<td>9</td>
<td>Student notes that assessment tasks extrinsically motivate them to study and learn the course material or get a good grade</td>
</tr>
</tbody>
</table>

Measure of learning

Measure of learning was one of the most frequently occurring themes as a purpose of assessment. This was noted by half of the participants. Several students noted that assessments, especially exams, tests, and quizzes measure how much they have learned and understood the material. For example, one student noted:

Because the exam is the measure of the product of our learning, I guess, you could say, of what we're retaining, what we're understanding. Are we able to work through problems? Are we able to apply this to different circumstances in the class? I think that's what the ultimate goal of that is. [U2CHE8]

In this quote, the student discussed how exams measure the content taught in the class that they were able to learn. This learning is tested through their ability to solve problems during the exam and apply the concepts to different situations. While most of the students did not elaborate on the purpose that might be achieved by measuring students’ understating of the content, one noted that this measurement is done to ensure that students are ready to move to the next level. Another student noted that in the first year, this measurement serves to weed out students who are not ready to pursue the major they are enrolled in.

Feedback on learning

As discussed above, not all students elaborated on the purpose achieved by measuring their understanding of the course content. However, two students noted that this measurement provided them feedback on their own learning. For example, one student reflected:

I feel like all these tests and quizzes are to assess, basically, where you are at in the course and either how far behind you are, how ahead you might be or if you're on the right track and so a lot of people might say, "Oh, these assignments tell the teacher 'oh, this is what I need to go over again,'" but usually no professors' gonna go back to
teach that again just for you. So for the most part, I think it's more independently you're able to assess what you need to review, what you need to go over, what you need to focus on in the end for the final. I think overall, it'll tell you what courses you need to put more into so you can do better. [U2CHE10]

As evident in this example quote, the student saw assessment as a way to figure out their own learning of the course material and the areas that require more attention from them. However, it should be noted that this feedback on their leaning is just for themselves and not for the professors to review some topics in the class that students might be struggling with.

Means to procedural approach to learning

Assessment as a means to procedural approach to learning was the biggest category in terms of the frequency of occurrence. More than two-thirds of participants noted that assessment provides them with an avenue for procedural approach to learning of both the course content and professional skills. Nineteen students reflected that assessment helped them to practice the course material to gain a mastery of course concepts and then apply these concepts to solve more complex problems, eventually leading to improved learning overall. As one student recounted:

The homeworks I would say are mostly to have some repetition of the topics in class, because just because you learn it in class and you see someone else doing it on the board doesn't mean that you necessarily can. And even if you can, you need to do it enough times that you know you understand it... I think the tests often combine different aspects that were so ... In a homework you might have one focus on this question, one focus on [another] question. A test can have those two questions combined. And so it's a little different from what you've been practicing, but you should ideally still be able to do it. So it's [about] can you apply the material? And that's how the lab report is. The pre-lab is like the homework, a specific question, but then the lab report it's like, can you combine these things and really apply them? [U1CHE13]

In this quote, the student described how different components of assessment help in procedural approach to learning. While homework and pre-lab activities provide the student an opportunity to gain mastery of a single concept through extensive practice, tests and lab reports require them to simultaneously apply different concepts on the same problem, thus fostering deeper and holistic learning of those concepts. Not only did assessment help students engage in procedural approach to learning, the learning gained through assessment also prepared them for the next steps such as upcoming tests and exams and courses that they would take in future semesters.

Some students connected the learning of content that happens through assessment to their future careers. One noted that the work they do for projects such as reports could be used as evidence of their learning to prospective employers. Another reflected that the content knowledge gained through practice will be used when they work as professional engineers.

While several students described how assessment provides an avenue for learning the course content, four of them noted that assessment helps them practice professional skills such as team work, communication, time management, and critical thinking. As one student recounted:

Like [in] <name of the engineering course>, the projects are... I believe the point of the class is to kind of give you the mindset of an engineer working in groups, critical thinking to complete assignments, being exposed to the kind of work that an engineer would be doing. [U1CHE7]

In this quote, the student described that the project work they were assigned in their first year engineering course exposed them to the kind of work that professional engineers do and
helped them develop important skills such as teamwork and critical thinking that will be helpful for their professional career. Thus, the student linked the development of professional skills through procedural approach to learning to their future careers.

Extrinsic Motivation for studying and learning

Besides helping students engage in procedural approach to learning, assessment was also seen as an extrinsic motivation for studying and learning. This purpose of assessment was noted by nine students. These students noted that assessments such as homework, quizzes, tests, and exams encourage them to study and learn the material. For example, a participant noted:

\[
\text{The purpose is to learn, and teachers are forcing you to do it [through assessment tasks]. Because honestly, okay, they are kind of a chore, but if we didn't have them, we would all fail because we would never review, except a few smart kids who care to review. Actually, maybe that's everyone but me. So, the purpose of the homework is in part to get you to learn, but I think the bigger idea is to force you to review the material. [U2CHE5]}
\]

In this quote, the student explained that homework, tests, quizzes, and project work encourage them to study and learn the course material. The student added that they thought of these as chores that are mandated by the instructors. As evident in the quote, the student felt forced by the instructors to complete the assessment tasks. However, in some cases, this motivation to study was largely guided by the desire to perform well and achieve a better Grade Point Average (GPA). For example, another student reflected:

\[
\text{I believe the purpose [of assessment] is to ensure that the students are absorbing and understanding the information. And the presence of cumulative assignments and graded assignments encourages the students to go and learn on their own because they know it will affect their grade and their GPA. So one, it encourages them to learn more in-depth and prepare themselves. [U1CHE3]}
\]

In this example, the student described how upcoming assessment tasks extrinsically motivate them to learn the material so that they could perform well and get a higher grade in the course, which in turn will lead to a higher overall GPA.

Discussion and implications

Situating students’ perceptions of assessment’s purposes within the literature

As discussed in the last section, students had varied perceptions of the purpose of assessment – measure of learning, feedback on learning, means to procedural approach to learning - that align with the existing literature on assessment. Our data also suggest an additional purpose of classroom assessment as noted by student: extrinsic motivation for studying and learning.

Assessment of learning as a purpose of assessment was present in the data in the form of assessment as a measure of student learning. However, since students did not specify what instructors and students could use the results of this measurement for, it is possible that some students, on further probing, could have cited the purpose of measuring student learning as formative. However, the formative nature of assessment (assessment for learning) was explicitly evident in the students’ view of assessment as a way to provide feedback for individual learning. Finally, assessment as learning was present in the data in the form of procedural approach to learning that students engaged in through the various assessment tasks. However, given the context of engineering, this procedural approach to learning was not limited to just the course content but also extended to the professional skills required of practicing engineers.

However, while the students’ perceptions of the purposes of assessment aligned with those present in the literature on the purposes of assessment, there were several nuances in how
students described the various purposes of assessment. First, while multiple students described at least one of the three purposes cited in the literature, none of them identified all three purposes of assessment. This suggests that, first year students, in general, do not have a holistic understanding of the purposes of assessment in higher education. Second, very few participants explicitly noted the formative nature of assessment, and those who noted the formative nature of assessment did not see assessment as a tool for course instructors. Meaning, students did not identify assessment results as a guide instructors could use to modify course content, teaching methods, and pace of teaching. However, it is possible that more students would have described the formative nature of assessment on further probing. Third, some students noted different purposes for different pieces of assessment. For example, tests and exams were generally seen as a way to measure student learning, homework was seen as a way to provide practice for the course content, and projects were seen as emulating the engineering workplace and hence provided practice for the engineering profession.

Besides the three purposes of assessment documented in the literature, our data also suggest an additional theme regarding extrinsic motivation, which denotes individuals’ motivation for engaging in an activity for instrumental or other similar reasons (Eccles & Wigfield, 2002). While for some students, this extrinsic motivation from course instructors who “forced” them to study by giving assignments, several students saw assessment as an extrinsic motivation for studying and learning so that they could perform well in a course and get a good grade. This approach to learning is similar to what Entwistle, McCune, and Walker (2001) call as the strategic approach to learning in which the students intend to get the maximum possible grade through putting well-organized and consistent effort in studying, managing time effectively, and finding the right materials that will help them get a good grade. This approach to learning is also consistent with Hattingh, Woollacott, and Reid (2017) who, in their quantitative study aimed at understanding students' learning behavior around assessment, found that students generally put in more work during the weeks they have assignments or tests due and generally use tests and exams as guides to decide the topics to focus on.

Implications for practitioners

The results discussed above have important implications for engineering instructors as discussed in this section. These implications relate to design of assessment activities and communicating the purpose of those activities to students.

With respect to the design of assessment, instructors should ensure that the classroom assessment given to students fosters deep approaches to learning. As discussed above, students see assessment as learning through practice and application of the course material. Besides, several students use assessment as the extrinsic motivation to study and practice the course material. As a result, a lot of their learning happens through completing the assessment. Hence, care should be taken that assessment methods push students to adopt deep approaches to learning. For example, tests based on multiple choice questions may not foster deep approach to learning while those based on open-ended questions that require explanation and elaboration may foster deep approach to learning (Struyven et al., 2005). Similarly, an immersive project experience will lead to deeper learning and increase transferability of learning to different contexts (Prince & Felder, 2006). Another implication related to students using assessment to guide their learning is that instructors should ensure that all course learning objectives are covered through assessment using methods that foster deep learning approaches. Moreover, given the increasing importance of professional skills in the engineering profession (Shuman, Besterfield-Sacre, & McGourty, 2005), assessment activities should also be designed to foster professional skills in students.

While attention should be paid to the design of assessment activities, it is also important that students are made aware of the purpose of different activities and how they should see and use results from an assessment activity. This awareness is necessary if the aim is to improve
student performance based on the feedback from assessment activities. Additionally, whenever possible, instructor should discuss students’ grades with them, and encourage students to provide them feedback on the assessment methods and teaching methods to make the process of assessment more formative for instructors as well.

**Future work**

While the findings from this study give important insights into how first year chemical engineering students perceive the purposes of classroom assessment, they also open the avenue for subsequent research. Future work can include an exploration for how students’ perceptions of the purposes of assessment change as they spend more time at the university. The participants for this study were first year students, who may still be in the process of understanding the functioning of the university and how and why different components are designed. To this end, data were collected from a select group of these students about their perceptions of the purposes of assessment.

A further analysis of the current dataset can also be done to get deeper insights into first year engineering students’ perceptions of assessment. Data were also collected to solicit students’ views of the fairness of the assessment tasks they are assigned. An analysis of the relationship between how students perceive assessment’s purposes and its fairness can be conducted to get a more detailed picture of students’ perceptions of assessment.

Future work can also be done to understand how instructors perceive the purposes of assessment that they give to students, especially at the first year level. This will help us understand if instructors and students have the same view of the purposes of classroom assessment and address any mismatch.

**References**


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The Role of Racial Identity in the Achievement Motivation of African American Engineering Students Engaged in Undergraduate Research Abroad

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Abstract: In a field underrepresented by African Americans and driven by global competence initiatives, research that investigates how international contexts contribute to achievement motivation among African American engineering students is warranted. One means for this investigation is through examining the role of racial identity. To examine how racial identity influences research-related achievement motivation while abroad, this study utilized the achievement goal theory and Multidimensional Model of Racial Identity (MMRI) frameworks. Data were collected through focus groups conducted from 2012 to 2017. The findings demonstrate that perceptions of how others view African Americans motivated participants to engage in research. Participants were motivated to represent their race through their performance. Pressure to represent one's race can become burdensome over time. Therefore, attention should be given to strategies that help release performance pressure experienced by this group. Addressing pressure to perform at the institutional level may have benefits that are transferable to international contexts.

Introduction

Participation in undergraduate research has been shown to benefit underrepresented groups in science, technology, engineering, and mathematics (STEM) (i.e., African Americans, Hispanics, and American Indians or Alaska Natives) significantly more than other students (Haeger & Fresquez, 2016). However, there’s a dearth of research that specifically documents the experiences of African American engineering undergraduates engaged in research in international contexts. One aspect of research abroad experiences that warrants attention is the role of racial identity in motivational processes. In international contexts where this population is perceived as the minority, racial identity may have a significant impact on one’s motivation to achieve while abroad. Due to the structural and historical factors associated with African Americans’ academic success, Graham (2004) expressed a need to investigate why they engage in achievement-related behavior rather than the
behavior per se. A racial identity framework provides a unique lens to capture the “why” of achievement-related behavior.

A strong sense of racial identity has been shown to be associated with the achievement of African Americans, but less is known as to how racial identity beliefs contribute to their motivation. Most of the research on racial identity and academic achievement question whether a strong sense of racial identity promotes or inhibits academic outcomes (e.g., Bryd and Chavous, 2011; Graham and Hudley, 2005). Although the literature documents a positive relationship between racial identity and achievement (e.g., Chavous et al., 2003; Hope, Chavous, Jagers, and Sellers, 2013), researchers have not detailed the process or mechanisms by which students’ beliefs of their race influence their motivation to achieve (Graham and Hudley, 2005). In the present study, the achievement goal theory (AGT) and the Multidimensional Model of Racial Identity (MMRI) was used to shed light on how racial identity promotes achievement motivation in an international research context.

Achievement Goal Theory

Achievement goal theory (AGT) provides a framework to explore the purposes students attribute to engaging in academic behaviors and reasons they persist in a task when faced with challenges (Elliot and McGregor, 2001). It categorizes two distinct orientations that describe goal-directed behavior: mastery and performance goal orientations. Students with mastery goals hold a self-improvement motive characterized by a desire to improve their competence and master the content or task (Elliot & Thrash, 2001). In contrast, students with performance goals are driven by a motive of self-presentation (Elliot & Church, 1997). These students either engage in academic tasks to receive positive judgments of competence (performance-approach) or to avoid appearing incompetent (performance-avoidance) (Elliot and Church, 1997). Based on the MMRI, racial identity is expected to influence goal-directed behavior through societal perceptions of African Americans. How African Americans perceive others to view their race may influence whether they engage in research for the sake of learning (mastery goal) or for the sake of proving their competence (performance goal).

Multidimensional Model of Racial Identity

Sellers, Smith, Shelton, Rowley, and Chavous’s (1998) MMRI is commonly used to address the significance of race in an individual’s self-concept. It also conceptualizes individuals’ subjective definitions of what it means to belong to their racial group. The model identifies four dimensions of racial identity: racial salience, racial centrality, racial ideology, and regard (private and public) (Sellers et al., 1998). The regard dimension, which is the focus of this study, reflects the meaning that individuals ascribe to being African American; it consists of a private and public component. Private regard refers to individuals’ affective beliefs or judgments about their race, as well as their feelings about being African American (Chavous et al., 2003). Public regard is defined as the extent to which African Americans feel others possess a positive or negative perception of their race (Sellers et al., 1998).

Public regard is considered an influential factor in how African Americans identify with their racial group (Sellers et al., 1998). It is predicted that acknowledging society’s devaluing of African Americans can either lead to a more negative judgment of their race or help individuals refrain from internalizing those negative messages received from society (Sellers et al., 1998). However, research has not shown which prediction serves as a more accurate account of the impact societal perceptions can have on individuals who identify with this group (Sellers et al., 1998). Regard is expected to influence achievement goals adopted in educational settings where race is made salient. Salience refers to the extent to which one’s race is a relevant part of one’s self-concept in a specific situation (Sellers et al., 1998). Race becomes the most salient in environments where one’s race makes the individual the minority. Integrating AGT and MMRI frameworks into one study enables an investigation into how the regard dimension of racial identity is activated in an international context and influences students’ motivation.
Literature Review

Achievement Goals and Racial Identity for African Americans

Achievement goals are driven by situational and contextual factors, and foster either maladaptive or adaptive patterns (Dweck, 1986). The adaptive and maladaptive characteristics of achievement goals can vary and may have different effects on the academic outcomes of individuals. For instance, a mastery goal orientation is considered the most adaptive pattern of achievement behavior and is characterized by challenge seeking and high persistence in the face of difficulties (Dweck, 1986). By contrast, a performance-avoidance goal orientation is viewed as maladaptive and characterized by challenge avoidance, low persistence, and diminished effort when faced with challenges or failure (Elliot & Church, 1997; Dweck, 1986). Performance-approach goals have the potential to promote processes that lead to achievement, but are not considered as adaptive as a mastery goal orientation (Elliot and Church, 1997).

For African American students, research examining the effects of achievement goal orientations on educational outcomes has yielded conflicting results concerning their maladaptive and adaptive patterns (e.g., Gutman, 2006; Long, Monoi, Harper, Knoblauch, & Murphy, 2007; Shim et al., 2008). For younger African American students in K-12 settings, performance goals have been shown to be unrelated to academic outcomes (e.g., Gutman, 2006; Long et al., 2007), while other studies have shown a negative relationship between performance goals and achievement (e.g., Shim, Ryan, & Anderson, 2008). At the undergraduate level, it has also been demonstrated that performance goal orientations are negatively related to academic performance for African American students (D'Lima, Winsler, & Kitsantas, 2014). Research at the undergraduate level, however, is sparse. With the conflicting findings regarding performance goals among African American students and limited research in higher educational settings, further research is needed to better understand the adaptive and maladaptive patterns of performance goals for this population.

In certain learning environments, African Americans’ adoption of performance goals may be explained by their racial beliefs and can prompt either positive or negative outcomes. Racial identity as a hindrance has been demonstrated in research on stereotype threat’s impact on academic achievement. Steele (1997) describes stereotype threat as occurring when negative stereotypes of the group to which one belongs is made salient and the individual fears exhibiting traits or behaviors that will confirm the stereotype. In a performance-based environment where there is a threat of being stereotyped, threatened individuals are expected to experience a sense of doubt or low expectancy (Steele, 1997). The emotional distress and pressure caused by the threat is then expected to undermine performance. Students with positive racial pride have been shown to be more susceptible to stereotype threat (Ho & Sidanius, 2009). Yet, racial pride has also been shown to be associated with positive feelings about school, positive self-beliefs pertaining to academics, and future educational attainment for African American students (Chavous et al., 2003).

The purpose of this study was to utilize the achievement goal theory and Multidimensional Model of Racial Identity (MMRI) frameworks to examine how African American engineering undergraduates’ perceptions of how others view their race influence their achievement motivation during a research abroad experience. In attempts to avoid confirming negative stereotypes, individuals with low public regard may engage in research to prove they can be successful (performance goals). Individuals who believe that others think positively about African Americans, however, may not perceive a need to “prove” their competence. In this case, mastery of the research task is the guiding motivation (mastery goals). The following research question guided this study:

To what extent does African American engineering students’ perceptions of how others view their race influence whether they’re more motivated to engage in research to develop skills or to prove their research competence?
Methodology

This study utilized a qualitative approach to examine African American engineering students' motivation to succeed in research during Howard University's Global Education and Awareness Research Undergraduate Program (GEAR-UP). GEAR-UP is a research initiative that fosters global development of African American STEM undergraduates through international research experiences. Since its initial launch in 2011, GEAR-UP has provided opportunities for 214 STEM undergraduates to participate in summer research experiences in a total of 16 different international sites in Africa, Asia, Europe, North America, South America, and Southeast Asia. Each host site has local university mentors and faculty members who work in conjunction with Howard University faculty to create relevant projects for GEAR-UP participants.

GEAR-UP’s targeted population is freshmen through non-graduating seniors with declared majors in STEM disciplines (e.g., Biology, Chemistry, Engineering, Mathematics, and Physics). Aside from being a STEM major, students must also be US citizens or permanent residents with a GPA of 2.5 or higher. Students eligible for the program are recruited at the beginning of the fall semester through information sessions, presentations in STEM classes, emails disseminated through listservs, flyers posted across Howard's campus, and word of mouth. All interested participants must complete an online application, which includes necessary demographic information and essay questions. In addition to the application, each student submits a resume, academic transcripts, and two letters of recommendations, preferably from STEM faculty. All student applicants are interviewed, and participants are selected based on a combination of factors not limited to the submitted documents, such as maturity level, emotional intelligence, and open-mindedness. Selection is also based on international partners' requirements, including majors, they are willing to host.

To examine GEAR-UP’s impact on student outcomes, data were collected through the phenomenological approach (Denzin & Lincoln, 2003) using interviews, focus groups, journals, and blog posts. Through the phenomenological approach, students' personal and collective responses are examined to better understand their experiences before, during, and after their participation in GEAR-UP. Participants were expected to participate in focus group interviews upon their return from the summer research abroad experience. Between 2013 and the fall of 2017, focus groups were recorded and transcribed for over 200 participants between the ages of 19 and 23. After transcribing each of the interviews from the audio recordings taken during the interview process, the data were coded by hand utilizing the Creswell's (2003) multistep process. The steps included: (1) organize your data, (2) review all the data to gather meaning, (3) code and gather data into categories or overarching parts (4) describe the categories created (5) use of a drawing or narrative to further describe findings from interviews, and finally (6) interpret the findings and themes. For this paper, responses to the interview protocol item, “Complete this statement: Being an African American engineering researcher abroad means”, were coded to identify themes pertaining to racial identity and motivation that emerged from the data.

Results

The dominant theme in the data is one of representation. GEAR-UP participants were driven by a motive of self-presentation and sought to demonstrate and “prove” their competence. The participants were more performance-goal oriented, as they desired to represent their race in a positive light as well as instil hope to other African Americans in STEM. Since GEAR-UP participants felt the need to represent their race both for other African Americans and for non-African Americans, the overarching theme of representation will be broken into two subthemes: “Trailblazer” and “Token Representative”. The “Trailblazer” subtheme reflects representation for the internal group (other African Americans) and “Token Representative” subtheme reflects representation for the external group (non-African Americans).
Americans). The following quote captures the overarching theme of representation and sets the tone for our theme discussion:

“It means you have something to prove; you have to prove that you can do this.”
(Male, Turkey, 2013)

“Trailblazer” – The Internal Audience

Some GEAR-UP participants adopted the responsibility of a “Trailblazer”. As a trailblazer, they saw their role to serve as an example or a role model. By participating in a research abroad program, participants believed they were blazing the trail for those to come after them. If they could model success, they felt it would open doors and pave ways for other African Americans to follow. As demonstrated in the following quotes, the participants believed that their success in research abroad demonstrated to other African Americans that success for them in this context is also possible.

“I think definitely we set some examples; we show people that—or African American students that are younger than us—that this is something that they can do.” (Male, Philippines, 2017)

“I want to say it means being an ambassador. It’s definitely like being an example to the other people who you’re coming back home to so that they know they can also do what you did. It’s not a mountain they can not climb.” (Female, Thailand, 2015)

“It means that I’m ahead of the curve. There are not too many people in general that can do something like this and to be an African American student doing it means a lot more. It’s like paving the way.” (Male, Indonesia, 2012)

“….knowing that you can study engineering and you can go abroad and you can do research—that’s really meaningful and it can be completely outside the understanding of the generation before me... They always say this generation is your grandparents’ modest dream. Just knowing that it is possible and knowing that I’m a part of it, made it really important to me. It’s really encouraging to know that no one probably thought it was possible. The fact that I’m already doing it means I have to continue.” (Female, South Africa, 2016)

“Token Representative” - The External Audience

In addition to the “Trailblazers”, some GEAR-UP participants adopted the role of “Token Representative” of African Americans and initiated this role of proving that African Americans are capable of successfully conducting engineering research. For many of the GEAR-UP participants, it was a realization that for the people they encountered abroad, this was their first time interacting with African Americans. As demonstrated in the exemplar quotes, participants viewed GEAR-UP as an opportunity to disrupt pre-established stereotypes. They believed that their success in conducting engineering research abroad would in some way reverse the negative image of African Americans.

“Giving the world a chance to see an African American in a different light. A lot of people were very surprised to hear that we were from America. I don’t know what they see. The only movie they had with African Americans was Coach Carter so it’s...
good for them to see that we know science not just rap and sports." (Male, Chile, 2012)

“Being African American in tech or STEM field, it was nice to let them know that we’re not behind. We are not like….we’re not dumb black girls just sitting here to be here. I can contribute to the project.” (Female, Thailand, 2013)

“You also have to have this mindset that I have to work harder; there’s always the next step that you have to take not only just to further the positive image of African Americans but also as positive image of an African American in engineering.” (Female, Romania, 2014)

“I would say it means that we’re capable like we actually have the ability to do research abroad in a sense we’re like the first of its kind. It’ll be good for other universities to see a group of African American students doing research abroad and actually being successful and us actually submitting papers that get published. I think it means just a gateway for the future for STEM—for African-Americans in STEM doing research.” (Female, Ethiopia, 2014)

“I feel like it’s definitely setting the standard… I kept that in the back of my head the whole time we were there. I’m like this might be this person’s first interaction with black people so I’m going to make sure I’m setting a good example so that they have a good experience. And because this is how they’re forming their opinion on black people, like with their face-to-face interaction, it’s really important to make sure that it was good.” (Female, Philippines, 2017)

**Discussion**

The findings of this study provide evidence for an association between one’s racial identity and achievement motivation. In this study, African American engineering undergraduates were driven to succeed by a motive of self-presentation. When asked to complete the statement of what it means to be an African American engineering researcher abroad, participants responded from a performance goal orientation informed by societal views of African Americans. In their responses, they were focused on their collective or group identity as an African American. According to social identity theory, individuals strive to maintain or enhance both a positive personal identity and a positive collective identity (Luhtanen & Crocker, 1992). While abroad, it was clear that participants strived to enhance their collective identity as African Americans. For them, doing so meant proving that they were able to successfully conduct engineering research in an international context.

In the case of GEAR-UP participants, a performance goal orientation was an adaptive response to an environment where their race and/or nationality made them the minority. In contrast to interfering pressure described by Steele (1997), our data presented a *facilitating* pressure. The pressure of confirming negative stereotypes of African Americans facilitated a positive motivational response rather than an interference with their performance. Students appeared to be more motivated to achieve simply because society does not expect it. The facilitating or adaptive response to the environment may be explained by an approach-success mindset. Performance-approach goal oriented individuals approach success with an eagerness to show their competence. In contrast, performance-avoidance goal oriented individuals are fixated on avoiding failure and not appearing incompetent. For one side, there’s some doubt in one’s ability, whereas the other side is characteristic of confidence to succeed. Since GEAR-UP recruitment is a competitive process, students interested in
GEAR-UP and then selected to participate are expected to be those with greater confidence in their abilities to conduct research.

The facilitating nature of the performance pressure may also be because GEAR-UP participants are not as vulnerable to the influences of negative societal views. For African American students, perceptions of societal views have been shown to have a weaker influence on their academic outcomes than their personal feelings about their race and about being African American (Chavous et al., 2003). The finding that negative perceptions of society facilitated GEAR-UP participants’ performance without a shift in their self-beliefs demonstrates that not all African Americans internalize negative ability messages. As previously mentioned, an awareness of society’s devaluing of African Americans has the potential to negatively influence students’ personal judgment of their race. For this group of students, this awareness is a form of motivation.

It must also be noted that GEAR-UP is a 4-week program. Continuous performance pressure over a longer period of time may change in nature from facilitating to interfering. Longer subjection to performance pressure may result in the maladaptive responses associated with performance goals, such as challenge avoidance and low persistence. In a field underrepresented by students of color, African Americans will find themselves in performance-based environments that call the representation of their race into question. The determining factor underlying whether a threat of confirming negative stereotypes facilitates or interferes with one’s performance is unclear. Further research is needed to gauge responses to performance threats and their association with racial identity or other factors unique to students of color. A focus on performance pressure for African American women—a double minority in most STEM environments—is also warranted.

The preoccupation with protecting or enhancing the image of African Americans can also be explained by the demographics of the sample. GEAR-UP participants were undergraduates enrolled at a predominately black university. It can be expected that students who pursue higher education at a predominately black institution have a greater sense of black identity and pride for their race. Since it is known that students with positive racial pride can be more susceptible to stereotype threat (see Ho & Sidanius, 2009), students from a historically black university engaged in research abroad may have a different reaction to their experiences. These students may experience different underlying motivating factors when placed in an environment where they are the racial minority. Future research that investigates the research abroad experiences of African Americans from predominantly white institutions may serve as a meaningful comparison of the unique experiences of the two groups.

With the findings of this study, engineering educators may begin to question their role in releasing the performance pressure experienced by African Americans in engineering. Addressing performance pressure at the institutional level may have benefits that are transferable to international contexts. At the institutional level, it is important to note that intervention is more external to the student than internal. Steele (1997) proposed a focus on the removal of situational threats rather than altering one’s internal belief system. The reason being that susceptibility to stereotype threat does not originate from internal doubts (Steele, 1997). Therefore, rather than a focus on personal dispositions, educators must evaluate how structural factors within the learning environment contribute to performance pressure.

Although published over two decades ago, Steele (1997) provides strategies for combating stereotype threat within educational settings that still prove relevant for today. In attempts to lift stereotype threat, he encouraged institutions to help students feel secure in the belief that their performance will not be held under the suspicion of negative stereotypes about their group. This security can be cultivated by positive faculty-student relationships characterized by high expectations and public acknowledgement of intellectual potential. Since ability-stigmatized groups are concerned about individuals in their learning environments doubting their abilities, faculty can attempt to remove this concern by demonstrating expectations of success rather than failure. If students believe those around them expect them to succeed,
there may be less felt pressure to perform—or more specifically, “prove” one’s competence. Positive faculty-student interactions have been shown to be positively associated with a sense of belonging (Booker, 2007), and a sense of belonging for ability-stigmatized groups can help improve their academic experience (Murphy & Zirkel, 2015).

Conclusion

Research has demonstrated how undergraduate research experiences (UREs) are positively associated with academic outcomes for undergraduates traditionally underrepresented in STEM (e.g., Haeger & Fresquez, 2016; Jones, Barlow, & Villarejo, 2010). However, if research experiences, both internationally and domestically, are coupled with performance pressure for African American students, how can educators be sure that UREs are not counteractive? In efforts to diversify the STEM pipeline, it’s vital to foster an engineering identity among underrepresented students. With that, it’s also important to remember that greater identification with the field is associated with a greater concern about how one is perceived or judged in that field. When you couple this with a susceptibility to stereotype threat, there’s space for pressures of performance to evolve. For GEAR-UP participants, this pressure facilitated motivation rather than an interference with their performance. However, the burden of proving one’s competence in environments where threats arise can begin to affect academic outcomes and psychological well-being.

References


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A Translational Effort Focused on Student Reflection in Engineering Education

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Abstract: Translational work is a challenge in engineering education. The purpose of this scholarly effort is to identify lessons emerging from a sustained translational effort in the context of supporting student reflection. Leveraging a research through design approach led us to identify three types of work in translational projects: choosing a just-enough definition, building a practice-facing framework, and creating practitioner-relevant offerings.

Introduction

Imagine a collection of engineering education researchers have produced a body of research on a subject of relevance to educational practice (e.g., active learning, motivation, inclusive teaching). Imagine further that it becomes important to translate the research such that educational practitioners can leverage it. Some questions that might arise in the translational effort include: How can the subject matter be explained to practitioners so that the practitioners appropriate understand the subject matter and align the subject matter to their current practice? How can the research be organized so that the research can be navigated by practitioners and can be shared widely? What can be offered to practitioners such that practitioners would be interested? In this paper, we we explore these types of questions.

It is powerful to imagine the budget for engineering education research worldwide for a recent year. While it is not possible to offer an exact figure, it is easy to see that the figure is large. Consider that there were over 10 major engineering education research conferences worldwide and that the U.S. National Science Foundation (NSF) has funded around 30 $2 million Revolutionizing Engineering Departments (RED) grants. That there is substantial investment in engineering education research represents significant progress.

A reason for investment in engineering education research is to propel improvements in engineering education practice (Duderstadt, 2007). Yet, changes to practice have been difficult to gauge and, in some cases, to sustain. One thing that seems clear is a sense that the pace of change and of impact is not sufficient. Concerns about the rate of change in engineering education practice suggest a gap in our knowledge.

Against this backdrop, what is being done to connect research and practice, a type of work known as translational work? There is work on diffusion of innovation, propagation plans, barriers, and learning communities (Gardner et al., 2019). One subset of this work is translational design, work that involves designing tools that can support educational practice. Those engage in translational work go in a variety of directions, creating toolkits, authoring books, developing websites, and offering consulting services. A focus on translational work is key to engineering education moving forward.

Research through design offers an approach that may have promise for advancing knowledge related to translational work. This paper focuses on what a research through design approach applied to an ongoing design effort surfaced in terms of knowledge to support translational efforts. Specifically, we asked: What insights concerning translational design efforts have arisen from a research through design effort in the domain of supporting student reflection?
Background

This project builds on a collection of efforts to support student reflection in engineering education as well as the methodological approach known as research through design.

Supporting reflection in engineering education

The focus of this translational effort is work to help engineering education practitioners leverage insights related to promoting student reflection, with an emphasis on insights generated during the four-year CPREE project. The Consortium to Promote Reflection in Engineering Education (CPREE) was established in 2014 to address the need for broader understanding and use of reflective techniques in engineering education.

The consortium was comprised of 12 diverse campuses (4 research-extensive, 4 teaching-focused, and 4 associates-degree-granting), with dedicated PI scholars from a variety of engineering disciplines. As the name suggests, the focus of the consortium is on helping engineering educators bring reflection activities into their teaching. While this could have been approached in many ways, we started with the assumption that educators across the 12 campuses were likely already using “reflection activities” in their teaching, which turned out to be correct.

The goal during the first year of the consortium was to document reflection activities already in use. To do this, campus PIs sought out educators on their campuses and interviewed them about reflection activities they had used with students in the past. Ultimately, over 100 interviews resulted in over 120 “field guide entries.” These entries, which contain a description of the reflection activity as well as “tips” from the educator who provided the activity, are currently available on the CPREE website (CPREE, n.d.). Interestingly, the process of interviewing some of these educators became an opportunity for educators to talk about teaching and their philosophy of education (Turns et al., 2015).

During the second year of the consortium, the goal was twofold: to get educators on the 12 partner campuses to incorporate reflection activities in their teaching and to collect, via surveys, information about how the reflection activities were supporting student learning. During the second year, the work of many educators leveraging many reflection activities resulted in over 60,000 student reflection experiences and survey data on around 3000 of these reflection experiences (for many reasons, surveys were passed along to only a subset of students). Further, reports from external evaluators surfaced additional insights.

Over the course of CPREE’s four years an extraordinary amount of research was collected—research around educators’ current reflection activities, the design of reflection activities, and students’ reactions to reflection activities. As the collection of research insights grew during the consortium, so grew the challenge of the translational work. CPREE itself culminated with a significant translational activity—a 1.5 day workshop in which over 50 attendees were challenged to design a new reflection activity by information generated during the consortium—information on existing reflection activities, on students’ perspectives concerning reflection activities, and information on educators’ perspectives on reflection activities. That 2017 workshop was followed by other translation efforts, notably the drafting of a book manuscript and the creation of series of fact sheets/worksheets.

For the past eighteen months, a goal has been to design tools that help engineering educators (i.e., the practitioners) make use of relevant parts of a substantial body of insights related to supporting reflection in engineering education (i.e. the research from CPREE). This design work has involved work in several material forms. We created resources for workshops which proved successful in social settings but not as stand-alone resources. We
started a book with formatted worksheets that made it easier to share content with others but felt uninteresting. We created a series of worksheets that we user tested but found the users felt they were prescriptive. Creating a reflective activity design canvas helped lay out the key elements of our framework but when we attempted to share the canvas it felt overwhelming. Creating a toolkit helped us de-center from the worksheet form to re-representing the underlying information in various physical forms. This paper is an opportunity to pause and ask what knowledge is arising from this sustained design effort?

Research through design

Research through design (RtD) is a method from human computer interaction that builds on the idea that designing is a powerful way to generate knowledge (Zimmerman and Forlizzi, 2014). The goal of RtD efforts is to concurrently engage in design while paying attention to the knowledge emerging. RtD is motivated by the challenge of connecting design and other forms of research (Stolterman, 2008). On a general level, the idea is that the knowledge produced is likely to be more valuable for design efforts since it stems from design efforts. In other words, the approach generates knowledge that is close to design and thus has potential to be useful to other designers.

Koskinen et al. (2011) identify three traditions within the RtD umbrella: the lab, the field, and the showroom. In the lab tradition, the focus is on creating and testing specific design solutions, with the emphasis being on the knowledge embedded in the solution. In the showroom tradition, the emphasis is on the design of provocative engagements that stimulate critical reflection, with a focus on the insights generated by the provocation. The final tradition (and the tradition with which our work is aligned) is the field tradition. Here, the focus is on sustained engagements with design, such as work using participatory design.

Zimmerman and Forlizzi (2014) describe the processes of RtD as design practice that is “more systematic and more explicitly reflective” and also “requires more detailed documentation of the actions and rationale for actions taken during the design process” (p. 168). In other words, RtD is a qualitative process where the designers are also researchers and their goal is to listen to the backtalk of the design process, paying close attention to critical incidents for insights that have the potential to help others. Rigor is achieved through techniques such as self-aware monitoring of the ongoing design efforts, paying attention to critical incidents such as key changes in the direction of the designing, and looking to the critical incidents for insights that have potential to help other designers.

A RtD approach can produce different types of knowledge including novel perspectives which help advance understanding of a situation and artifacts that both “sensitize the community to the issue and broaden the space for design action” (Zimmerman and Forlizzi, 2014). In contrast to other research approaches an RtD approach assumes there is value in the framing of a design problem since framing involves abduction specific to a problem situation.

In some cases, an additional benefit of RtD is a type of efficiency and opportunity for sharing of knowledge. RtD focuses on capturing knowledge that might be otherwise lost by making it possible for more people to be aware of the research. In a traditional design situation, the design team becomes more knowledgeable but others in the community may not benefit from the insights resulting from a design effort. Thus, an RtD approach to capture and share emerging knowledge with a broader audience and more people seems promising.

Approach

The dataset for this RtD effort consists of the material artifacts associated with the various design efforts, field notes associated with key decisions, records of design directions, and feedback from users given in relation to prototypes.
Our approach for this paper started by identifying three activities involved in translational work: defining the central issue, building a framework to organize research on the issue, and creating something to offer practitioners. With these activities in mind, we

- Thought historically by revisiting our work and identifying critical incidents and pivots in how we approached the activity;
- Surfaced the doubts that associated with the critical incidents and pivots, and sought to understand the tensions and issues underlying the doubt (Locke et al., 2008);
- Considered theoretical perspectives that could be used to bring the tensions and issues into focus, and more toward useful insights;
- Identified a way to name/frame the way each activity that has emerged as central in our translational work, and finally
- Identified questions raised by our framing of each activity.

In a RtD effort, data analysis is collaborative, iterative and critical. This work is collaborative because the researchers (i.e., the authors) collectively reviewed the history and materials to co-construct meaning from the data and ultimately the findings presented here. The work is iterative in that the goal is to arrive at points or insights that repeatedly show up as valuable. Finally, the work is critical in the sense of seeking assumptions. In particular, we are motivated by Locke et al.’s (2008) suggestion that scholarly communities attend “to the living condition of doubt and its underappreciated significance for the theorizing process.” Thus, we chose to attend to the doubt in our translational scholarship. Experiences of doubt represent opportunities for learning. We also focus on challenges since ongoing challenges represent problems that are presumably harder than expected and thus deserve attention.

Results

In this result section, we discuss the ideas of choosing a just-enough definition, building a practice-facing framework, and creating practitioner-relevant offerings.

Choosing a just-enough definition

Definitions are important for translational work, but what type of definition is need for translational work? In our work on reflection in engineering education, we currently draw on use two key definitions: (1) reflection as a form of thinking that involves stepping out, thinking about, and connecting forward, and (2) reflection activities as configurations created by educators in order to support learner engagement in reflection. Our sense of what kind of definition and with what features continues to evolve.

History. Here are three snapshots of engaging with definitions in our work.

- Creating a 63 word definition. Concurrent with starting CPREE, we published a review of literature related to reflection in engineering. There we offered the following definition: “Reflection on experience can be framed as an intentional and dialectical thinking process where an individual revisits features of an experience with which he/she is aware and uses one or more lenses in order to assign meaning(s) to the experience that can guide future action (and thus future experience). We can use pathways of reflection to delineate combinations of these elements” (Turns et al., 2014). We had developed this lengthy definition to honor the wide range of scholarship we reviewed on reflection. In addition, we developed this comprehensive definition to stimulate conversation with others.
- Not using a definition. Over time we found that our lengthy and comprehensive definition created as many problems as it solved. Not everyone understood the definition and even more, the hoped-for nuance of the definition seemed to often create barriers to engagement. We also noticed that it was possible to have conversations about reflection without defining what we meant or by using images rather than words (e.g., someone on
top of a mountain) to convey our meaning. Although we were met with occasional challenges (such as a moment in a keynote presentation when an audience member suggested that they did not understand the talk because they had lived their whole life without reflecting), we made extraordinary progress with few instances of defining. Of note, most of the work during the consortium period was with people who self-selected into conversations, which meant we negotiated the meaning of the term reflection in real-time.

- Discovering a definition. Surprisingly, the current definition for reflection emerged as a solution to solve a specific problem for a publication: organizing patterns in how reflection activities scope the “past”, the “present” and the “future.” We were looking for pithy and catchy ways to organize the findings, and only later realized that these three phrases had power as a way to define reflection and appropriately convey what we meant.

How does doubt fit into this story? For a period of time, we questioned the need for a definition at all. If people could be generally on the same page without a definition, why create new problems when offering others a definition that might not align with their definition? This questioning was coupled with frustration--frustration with the unintended consequences of definitions because of our intent to be inclusive. In particular, definitions can function to signal who can be in a conversation and who feels left out (i.e., aligning with a definition is a means to know if you belong in a conversation). As we continued to have trouble with definitions, we moved away from definitions. It took a while to consider that we had we were having challenges because we had not yet found the right kind of definition.

Embracing this doubt led us to generate questions about defining--What does it mean to define? Who gets to define? What are the consequences of defining in translational work?

Considering theory. There are a variety of theoretical ideas that can be brought to bear on the history and doubts identified above. For example, while the notion of definition tends to conjure images of a complex propositional view of definitions, there are other ways to define (e.g., axial categories, prototype categories). Moreover, there are many functions for defining. It is possible to think about the role of shared meaning in coordinated action and in coalition building or about using related, known concepts to make sense of a larger conceptual idea. We observe that not all definitions function to convey truth. Rather some definitions may function to align existing practice and to make the familiar even more familiar. These thoughts led us to think deeply about what we were trying to achieve in this work and illuminate tensions around definitions; such as a definition being precise and a definition being generative.

Moving forward. The thinking illustrated by the thoughts above led us to identify the just-enough definition as a potentially important idea for translational work. For translational work, a just-enough definition is one that provides enough information for the practitioner audience to appreciate the work contained in the research and to be interested. A just-enough definition creates a foundational alignment and a bridge. At the same time, a just-enough definition can have its own challenges. For example, how is one to know if what is identified as “just-enough” is in fact not enough for the particular audience? What if the just-enough definition is too broad and permits too much? When the just-enough definition is successful, it builds a foundation and readiness for engaging with the relevant research and thus creates the need for that research to be organized.

Building a practice-facing framework

A second key activity for translational projects is building a framework to organize the relevant research. What, though, is important in building such a framework? The framework follows the design process where educators can work on a reflection activity through efforts to identify their input (e.g. how many students), think through various dimensions of the
activity they are designing, think about the kind of **engagement** they want to design for students and consider the potential **outcomes** of the engagement. These dimensions of input, activity dimensions, engagement, and outcomes are considered for not only students but also the educators implicated in the reflection activity. Across the top of the framework, there is space for the student perspective on these three and across the bottom there is space for the educator perspective. In this embodiment of the framework, we have given the most space to the **engagement** but also have attended to the entire reflection activity. Figure 1 shows a laser cut puzzle that we have been using to have conversations about the framework.

Figure 1. A framework for organizing research associated with support student reflection in engineering education, implemented as a laser cut puzzle.

**History**. Here we share three snapshots of engaging with frameworks in our work.

- **Running workshops.** For the final workshop in the consortium, we organized discussions that were activity centered, learner centered, and then educator centered. This tiered framework helped us organize discussions with our workshop participants but we never explicitly shared the framework to our practitioners. Rather we used this framework to guide our discussions and the structure of the workshop.

- **Writing a book.** Inspired by the workshops, we drafted a book to share our research with a broader audience. shows our attempt to take the resources we created for the workshop and put it into a framework that could be shared with the public in print. But this framework felt unsatisfying because it was not specific enough to the practice of designing something into existence or account for something that was already happening.

- **Giving a keynote.** We were invited to give a keynote using the framework we had built up until this point. We found ourselves negotiating how we might structure the talk based on our framework and how the audience might respond to it. The educator had been a shadow in our framework but it felt unsatisfying that we did not explicitly have a place in the framework for the knowledge and experiences the educator brought as a practitioner. Approximately two months later, the current version of the framework we developed includes the practitioner in all parts of the framework. We embraced the doubt and came to generative questions that helped us iterate on the framework to where it is now.

**How does doubt fit into this story?** As we worked to build our framework, we would ask ourselves where x could fit? As it became evident that we had missed something in the current version of the framework, we asked where do these new products of reflection or how
does identity fit in the framework? Is there a place for behaviors that emerge during the activity or a section for self-reports of how the activity went? As we explored these questions, we thought back to our just-enough definition that we had been using. Could it be possible to tell a simple story through the framework given how broadly we had defined the situation? We felt we had a plethora of insights but were overwhelmed with the need for structure and how that structure might enable us to explain the practice-facing framework easier.

**Drawing on theory.** Inspired by feminist perspectives, we use the notion of residual categories (Star, 2010) to make visible the invisible work of practitioners, to honor elements of the human experience (reactions) and particular humans in the experience (educators). Our just-enough definition of reflection had been so broad that the number of categories we needed to be accounted for in the framework was broad. Central categories emerged and became core features of our framework but we felt compelled to explore what the larger implications of residual categories like reactions and the current practices of the educator were. We paid attention to those residual categories, attended to them, and made them features of our practice-facing framework in an effort to not let go of residual categories.

**Moving forward.** Making our doubt generative helped us arrive at the practice-facing framework we have today. Yet, we are still dealing with the design tension of what counts, what gets to count, and who counts in the framework? When we create a framework where lots of things can count (and not lose residual categories which might make some work invisible) it has become complicated again. We are thinking about all the features our framework currently as we hope to make it practitioner focused. With so much on the table now, we are asking ourselves who wants what? What exactly do specific practitioners need help with? This leads us to our third difficulty we introduce in our translational scholarship.

**Creating practitioner-relevant offerings**

A translational effort results in something that is offered to a practitioner to support their practice, but an offering with what type of features? In our work, we are still in the process of exploring what our practitioner-relevant offerings could like but some of the things we have already offered include workshops, worksheets, a website with reflection activities, and cards showing reflection activities.

**History.** Here we share three snapshots of engaging with offerings in our work.

- **Offering workshops.** We have organized and offered workshops where a significant number of people from our community show up, express interest, and are engaged. The workshops result in many conversations where we, as facilitators, signal different visions and collectively with workshop participants negotiate our framework. Workshops create a social situation where we can respond to circumstances collaboratively. But we also know a workshop is separated from practice. Educational practitioners cannot go to a workshop every time they might need resources to support their practices.

- **Creating materials for individual use.** In addition to workshops, we have created a variety of materials that we can offer practitioners in different forms. We took workshop resources and transformed them into standalone offerings in the form of worksheets. During user testing, we noticed that some of our worksheets induced a "filling out" quality. We began to imagine how a framework might help practitioners with the documentation of a reflection activity and help them think through things on a canvas. Yet, these opportunities to present the framework as a canvas for personal use fell short when we started to share it with practitioners. In private conversations, the practice-facing framework as an offering felt overwhelming for practitioners, it bored others, and some were less interested in what we had to offer when we presented them with the entirety of the framework.
Engaging in customer discovery. Most recently, we have been engaged in customer discovery (talking with customers to discover their needs) through a small innovation grant we received. In this process, we have been developing value propositions where we explore the promise of value to be delivered to practitioners. Our most recent customer discovery conversations about pain points have shed some light into what we were missing in our prior efforts to create offerings which practitioners are actually excited about. Through these conversations, practitioners identified specific situations in their practice where something went wrong and shared with us what they would like in that particular instance. We have learned it is not only an challenge of needing inspiration, as we hypothesized previously, rather it might be an challenge of getting stuck and needing help in a particular moment.

How does doubt fit into this story? When sharing with others our experiences with customer discovery and a focus on value propositions, people have reacted with “isn't that a tired marketing thing?” or is that “just a business thing?” These questions did not align with our feelings that the process of going through customer discovery felt useful and refreshing. Another doubt associated with our recent customer discovery work has to do with experiences of being surprised. We have spent a significant amount of time talking to people through our scholarly endeavors that when we learn something new from our conversations with practitioners, we find ourselves asking “Should we not know that already?”

Drawing on theory. In engineering education, we have ideals about effective educational practice, i.e., forms of evidence-based practice. We find evidence that a certain educational practice can have desirable outcomes, and then think these practices can be passed along to practitioners. From an practitioner standpoint, when others recommend the best practices you should be enacting, without necessarily asking what you are already doing or honoring the many years you have as a practitioner, it might feel disrespectful. The practitioner knows themselves and their ultimate particular best. Our commitment to honoring the practitioner is informed by feminist scholarship which honors invisible work and respects the professional knowledge of the practitioners.

Moving forward. As we continue our efforts of creating practitioner-relevant offerings, we are staying with the trouble while we balancing researcher and the practitioner views of practice. Creating practitioner-relevant offerings means helping educators with what they need help with, on their terms, and attending to learning. As we negotiate this tension with respect offerings, we highlight that a practitioner focus is not meant as an excuse to stop attending to learning, but perhaps to honor the immediate, the trust that learning is always there as an interest of the practitioner. Though, there is a chance we might find out that existing practices of practitioners are already aligned with learning goals.

Discussion

This RtD effort has surfaced three types of work in translational work that have been significant in our project and have potential to help others. Specifically, we have identified a just-enough definition as important for the translational challenge of choosing a definition, a practice-facing framework as a guide for the translational challenge of organizing the research, and practitioner-relevant offerings as a guide for the translational challenge of deciding what to offer practitioners.

There is an underlying feature of these findings that continues to cause doubt. Each of these findings has a practitioner implicit in its construction: Just enough for whom? Whose practice is being faced? Whose perspective is important? So, the practitioners and not just the practice are critically implicated in our findings.
Interestingly, many years ago, Latour wondered “where are the missing masses?” In his work, he was advocating that researchers look to the artifacts to address the doubt implied in the question. In our work, as in Latour’s, we are struck that something is missing. In our work, though, we wonder about the missing humans, the missing practitioners, those who individually and collectively are supporting students, those whose practice needs to change as a result of the research. We note that it is ironically hard to write about practitioner educators. Lawyers practice law, doctors practice medicine, but educators in higher education come in all forms and rarely hold one label. In order to make more progress on translational efforts for educational practice, we may need to pause and address a terminology challenge related to the educators themselves. If we cannot even find a shared name, how can we begin to find the people who do the work. The practitioners in engineering education are ironically very much present and yet invisible.

Conclusions

This work contributes to the growing body of scholarship related to translational efforts. We identify three challenges from our design efforts: (1) Choosing a just-enough definition, (2) Building a practice-facing framework, and (3) Creating practitioner-relevant offerings. For each difficulty, we discuss how we embraced the doubts we experienced which led us to explore generative questions around definitions, frameworks, and offerings. We hope this work will serve other engineering educators seeking to engage in translational efforts. In addition, a contribution of this work lies in how it introduces the RtD approach to the engineering education community as a way of connecting research to practice.

References


Extent and Depth of PBL Implementation – Survey results from over 300 PBL-implementing US engineering educators

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Abstract: PBL and its variations have been implemented to varying degrees to support engineering education reform in the USA. This paper presents the results of a large sample of US engineering educators (non-representative) using PBL in their teaching practices, exploring the extent and depth of their implementations with particular respect to differences between junior and senior faculty. Findings indicate that PBL implementations varied and commonly desired and actual support for implementation showed strong similarities between faculty groups. Results from this study can guide faculty development and support. Further research is necessary to show mechanism and provide great depth.

Keywords: engineering education, faculty perceptions, implementation, PBL, problem-based learning, project-based learning

Introduction

One of the learner-centered pedagogical models used in engineering in the USA is Problem-based Learning (PBL) and its variations such as project-based learning (PjBL) problem-oriented project-based learning (POPBL) and the variety of design-based curriculum initiatives in engineering education. For this paper, PBL is described as a (1) supported learner-centered environment that (2) makes use of real-world design, project, or problem scenarios; (3) produces multiple possible solutions (complex, open-ended); (4) changes the role of instructor to predominantly facilitator/guide and (5) students are engaged in active learning. PBL serves as the basis for learning technical and process competencies, and for developing professional attitudes and interpersonal skills. While there seems to be a movement and an increasing knowledge base on PBL in engineering education, (Guerra, Ulseth, & Kolmos, 2017; Yusof et al., 2016), the extent and depth of those implementations remain unexplored. Results from such a study can provide insight into teaching practice and can guide faculty development and support.

Context

The purpose of this study was to investigate the extent and depth of PBL implementation amongst engineering educators in the USA who have experience with PBL implementation. This study does not claim to be representative for the whole population of US engineering faculty nor include representative numbers for PBL implementation within the US.

To analyse existing literature, the research team purposefully selected 35 studies to document the reported use of PBL in engineering. This was, by no means, an exhaustive search for articles, yet was intended to provide a preliminary view of the scope of PBL in engineering education. For the most part, PBL was implemented at the course level in all years of the program, although the literature includes strong advocacy for a full curricular
implementation (Hung, Jonassen & Liu, 2008). Dong and de Graaff (2009) stated that “…problem based learning can be an instructional strategy and in some cases it tends to be used within a subject or as a component of a programme or module” (p. 3), while Lacuesta et al. (2009) espoused that “…PBL must be the base of the educational curriculum and not just a part of the educational curriculum” (p. 2). Kumar and Hsiao (2007) advocated for integration of process skills via PBL throughout the program and not just for execution in a capstone course or project. Savage, Chen, and Vanasupa (2007) concurred and suggested that it was optimal to integrate PBL into the entire curriculum and not just have it support one experience, like a capstone project. However, implementation beyond the course level is yet to be evidenced in the research literature to any large extent.

To explore the extent of implementation of PBL in engineering education in the USA, our research questions included:

1. To what extent are engineering educators implementing PBL in to their teaching practice?
2. What PBL components are most and least frequently implemented?
3. What supports are most valued by engineering educators for PBL implementation, and to what extent are those supports in place?
4. How do results differ between junior and senior faculty members?

This research is important for engineering education, as it explores the unique need for PBL-specific support for faculty to implement this innovative and effective pedagogical approach to training tomorrow’s engineers.

Methodology

The reported research falls in the category of survey research and exploratory research. As the survey is not a psychometric instrument, questions of validity and reliability are not relevant, yet we tested the instrument for usability with colleagues and audience members. We recruited participants via emails distributed to professional engineering associations and engineering faculty in the US. The initial survey responses were checked for the following inclusion criteria: (1) teaching at a degree-granting higher education institution in the USA, (2) holding a faculty position, (3) teaching in engineering, and (4) implementing PBL at least twice within the last 2 years. The survey resulted in an n=327. Data were analysed with descriptive statistics.

The following describes our participants in more detail: From 327 participants, 56% reported to teach at research-intensive doctoral granting universities and 44% reported teaching at non-doctoral granting universities which include baccalaureate only and teaching intensive master colleges and universities. From our overall participant population, 72.5% reported to be male, 25.7% female and 1.8% reported no answer. Given recent data on representation of female faculty in US colleges of engineering, identified as 16.9% in 2018 (Yoder, 2018), female faculty as 25.7% are overrepresented in our participant group.

From the 327 faculty member, 31.2% held the rank of pre-tenure tenure-track faculty, 68.8% were tenured faculty (respectively identified as Junior and Senior in the rest of this paper). In addition, 37.3% (122) also held administrative positions. Of the 122, 15 (12.2%) were held by Junior faculty and 107 (87.7%) were held by Senior faculty.

Findings and Discussion

Faculty readiness. Participants were asked how they prepared to implement PBL in to their teaching practice. By far, the majority indicated that they were self-taught. While survey results indicated many similarities in preparation such as co-teaching and receiving formal training, some differences between Junior and Senior faculty are noticeable. Junior faculty reported a much higher rate (nearly double) of experiencing PBL as a student themselves...
and seemed to observe PBL classroom implementations more. It comes as no surprise that Senior faculty members have been coached less by mentors, as Senior faculty are most likely “first-generation” implementers (see Figure 1).

**How did you prepare to do PBL?**

<table>
<thead>
<tr>
<th>Prepared to Implement PBL</th>
<th>Junior (n=102)</th>
<th>Senior (n=225)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Experienced PBL as a student</td>
<td>65%</td>
<td>54%</td>
</tr>
<tr>
<td>Self-taught</td>
<td>23%</td>
<td>11%</td>
</tr>
<tr>
<td>Received formal training</td>
<td>71%</td>
<td>32%</td>
</tr>
<tr>
<td>Co-taught with a colleague who was doing PBL</td>
<td>35%</td>
<td>44%</td>
</tr>
<tr>
<td>Was coached/mentored by a colleague who was doing PBL</td>
<td>23%</td>
<td>17%</td>
</tr>
<tr>
<td>Observed PBL classroom implementations</td>
<td>65%</td>
<td>54%</td>
</tr>
<tr>
<td>Other</td>
<td>22%</td>
<td>44%</td>
</tr>
</tbody>
</table>

Figure 1: Ways faculty prepared to implement PBL

**PBL implementation.** Faculty were asked to select all program years in which they implemented PBL. As is to be expected, the majority of implementations for both Junior and Senior faculty were in the later years of the program (see Figure 2). A primary driver for the implementation of PBL in the later years of engineering programs has been the need to have students apply knowledge and transfer their skills to novel situations and open-ended problems (Ahern, 2010; Nasr & Ramadan, 2008; Yadav, Lundeberg, Subedi, & Bunting, 2010). In addition, senior capstone courses - which share features with PBL learning environments - have been widely implemented across US engineering.

For the research team, the reported PBL implementation in graduate level courses was surprising and would warrant further discussion and additional research in the future.

**In what year do you implement PBL?**

<table>
<thead>
<tr>
<th>Year</th>
<th>Junior (n=102)</th>
<th>Senior (n=225)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grad</td>
<td>54%</td>
<td>31%</td>
</tr>
<tr>
<td>YR4</td>
<td>51%</td>
<td>33%</td>
</tr>
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<td>YR3</td>
<td>54%</td>
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</tr>
<tr>
<td>YR2</td>
<td>45%</td>
<td>35%</td>
</tr>
<tr>
<td>YR1</td>
<td>39%</td>
<td>23%</td>
</tr>
</tbody>
</table>

Figure 2: Years faculty implement PBL (multiple answers possible)
Existing literature mentions that PBL implementation in the full engineering curriculum (all courses) is rather rare (Litzinger et al., 2011), our data further suggests while slightly more than half of our surveyed faculty implement PBL as a whole course design, a large majority of faculty are implementing PBL even to a smaller degree as modules within an otherwise non-PBL designed course (see Figure 3). The extent of PBL implementation raises an important concern about the interpretation of what is considered PBL and the integrity and fidelity of the proper implementation. If a standard of what PBL is and fidelity in the implementation cannot be guaranteed, future research into any implementation related issues (such as efficacy, challenges of implementation, etc.) will be difficult to conduct.

Additionally, we asked faculty members to what degree PBL courses make up their respective workload. As one can see in Figure 4, a wide majority of junior and senior faculty reported that either all of their courses are PBL courses or a majority of their classes are taught in the PBL format. It is surprising, however, that more Junior faculty reported that their entire teaching workload is comprised of PBL classes as existing research on barriers indicate that PBL teaching, while more demanding, does not receive the support or credit it deserves (Strobel & van Barneveld, 2015).

**Implementation of PBL components.** Participants were asked the extent to which they implemented PBL components into their teaching practices by either clicking “always”,

---

**Figure 3: The extent of faculty uses of PBL in a single course**

**Figure 4: The extent of faculty use of PBL in their teaching workload**
“often”, “sometimes” or “never”. The components of PBL were taken from existing published work on PBL (Barrows, 2002; Savery, 2006; Strobel & van Barneveld, 2009, 2015) All scale data were normalized to produce a single score for each of the implementation categories in order to facilitate an easier overview and overall comparison. “Normalization of ratings means adjusting values measured on different scales to a notionally common scale, often prior to averaging. In more complicated cases, normalization may refer to more sophisticated adjustments where the intention is to bring the entire probability distributions of adjusted values into alignment” (Dodge, 2006, p. 340).

As seen on Figure 5, the least component used across all instructors in our sample are items related to reflection - either the process, in which students (Ss in the graph) reflect on their learning progress or the teaching of knowledge and skills related to students' reflection. Similarly low are also self- and peer assessments which require either reflective or metacognitive skills as well. It is surprising that the score for “real world problems” is fairly high (.59), yet the score for “problems are interdisciplinary” (.40) and “problems are open-ended and allow free inquiry” (.53) are lower. One feature of real-world problems is that they tend to be by definition interdisciplinary and lend themselves to multiple possible solutions. Our data would indicate that instructors might introduce real-world problems, yet ask students only to work on a narrow disciplinary component of the problem presented.

In addition, it was encouraging to see that faculty report that part of their teaching efforts, students are encouraged to take ownership of their own learning processes and so in effect become more autonomous and self-directed learners. Given that PBL has an undeserving reputation for being minimally guided and students are not adequately supported (Hmelo-Silver et al., 2007), it would be interesting to further research how the ownership aspects manifest themselves in the teaching practice and how students demonstrate their ownership in the learning process.

![Figure 5: Extent of PBL components in Teaching Practice (Least to Most)](image_url)

Comparing Junior and Senior faculty's use of individual PBL components (see Figure 6), we see that for all components, Senior faculty report implementing them more - sometimes a lot more like, for example, when it comes to “problem serves as driver for learning” and sometimes the difference is marginal, such as in the use of "small groups as collaborative..."
teams”. It is important to note that more refers to a trend and not a statistically significant difference.

Figure 6: Extent of PBL components in Teaching Practice (Junior and Senior)

For additional investigation into the specifics, we researched the components for which participants provided a higher number of “never” as an answer and analysed them to compare Junior and Senior faculty members. With regard to integrating student self-assessments and peer-assessments, 18% of Junior faculty and 9% of Senior faculty indicated that they never implemented this component into their PBL practice (see Figure 7). Adding to the “never” the “sometimes” and we have over 50% for junior faculty and near 50% with senior faculty.

Figure 7: Use of component - Student self- and peer-assessment

Reflection is another important aspect in the PBL process, supporting the development of critical thinking and metacognitive skills (Marra et. al, 2018; Johansson & Svensson, 2019) and the cornerstone of why students learn in PBL classrooms (Hmelo-Silver, 2004). Whether reflection focuses on the process of learning or on the acquired knowledge and skills, a number of faculty never implemented these components into their PBL practice - Junior faculty having a higher incidence of never using reflection than Senior faculty (see Figures 8 and 9). It would be worthwhile for further research to investigate the lack of reflection
elements in PBL environments and leverage elements to increase the use of reflection not only in PBL environments but in all engineering classrooms as well.

![Figure 8: Use of component – students (Ss) reflecting on their learning (process)](image)

**Figure 8: Use of component – students (Ss) reflecting on their learning (process)**

![Figure 9: Use of component – students (Ss) reflecting on their learning (knowledge and skills)](image)

**Figure 9: Use of component – students (Ss) reflecting on their learning (knowledge and skills)**

**What is desired and actual support when teaching PBL.** Participants were asked to rate the desired (valued) support items for their PBL implementations and the actual support they receive. Favourable teaching/learning spaces, budget for materials, industry support, and release time for course design were the most desired/valued support items by both Junior and Senior faculty (see Figure 10). While support from industry seems to be more aligned for Senior faculty (desired vs actual), it is less so for Junior faculty. For the other three top-rated supports, the gap between the desired and the actual provision of support appears large for both Senior and Junior faculty. It is not surprising, however, to see that both release time and teaching assistants (TAs) were the least actual given that both represent heavy financial incentives.
Conclusion

This survey-research investigated the extent to which PBL is implemented in US engineering and what, what components are implemented, the support valued by faculty and differences between junior and senior faculty. The first surprising result was the amount of engineering faculty filling out the survey. We take our higher than expected return rate as an indicator that PBL arrived in the mainstream of engineering education. The results indicate that PBL implementation varies and core features of PBL have not been reported as being consistently implemented. Furthermore, while nuanced differences between Senior and Junior faculty appear to be present, many shared concerns, desires and ratings of their actual support emerge. The higher-rated desires for support should inform administrators and leadership when looking for implementation for new pedagogical models. Our research drew from a large list of agreed-upon components of PBL implementation. Our research has found that even for the most used components, they often are only used sometimes or infrequent.

Implications and Future Research

Research on the extent of PBL implementations, and desired and actual support for PBL implementations, have not been conducted yet to the scale of this paper. This study does not claim to be representative for engineering educators in the US nor representative amongst PBL implementers in the US. For a larger contribution to the knowledge, our research indicates that interpretations and implementations highly vary with huge implications for research and practice: We need finer grained and more precise ways to talk amongst ourselves about the practices of our teaching and should not assume that one’s instructor PBL is another faculty’s PBL. Future research could provide more nuanced results and provide more answers to why and how variations of PBL are being implemented and how we can utilize the rich understanding for improving engineering education practice.

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Barrows, H. (2002). Is it truly possible to have such a thing as dPBL? Distance Education, 23(1), 119-122. doi: 10.1080/0158791020124026.


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The impact of prior transport-based experiences on academic interest and performance– a case study of undergraduate students in Transport Science modules at Stellenbosch University

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Abstract: Transport Science 324 and 364 form part of the curriculum of the BEng Civil Engineering degree at Stellenbosch University. Transport Science incorporates tangible theories and real-world application and therefore lends itself to a constructivist theory of learning which considers knowledge to be developed by building on existing knowledge acquired through past experiences. Each year, some students perform particularly badly in Transport Science; this research investigates if there are systemic reasons for their failure to thrive with the material. Particularly, this research investigates the influence of previous exposure to multiple traffic environments on students’ interest and fundamental understanding of traffic relationships. Transport Science students from 2018 completed an online survey gaining information about their past exposure to traffic and transportation situations. This was compared to their academic performance in Transport Science, providing insight as to whether students performed either better or worse in Transport Science than prior academic performance might have predicted.

Introduction
All universities face continual pressure for curriculum change, as dominant knowledge paradigms across the world change, and as economic circumstances of students shift to reflect global financial uncertainties. Some of the changes being considered are made possible through advances in technology (distance learning options, for example, which are being grasped by many universities, offer opportunities to expand student numbers) but these can bring into question the relevance of old content and assessment techniques.

One of the strands of continual change facing universities in South Africa is the need to cater for a wider social spectrum of students. Under apartheid, universities were elite institutions serving predominantly white middle classes. The abolition of apartheid and the opening of universities across racial and economic divides since that time has meant that the typical student body is irreversibly altered. The benefits of wider social inclusivity in universities are enormous, not least (from a scholarship perspective) because the diversity of students presents new pedagogical challenges and opportunities in the lecture theatre and the laboratory. The debate around colonialism of knowledge, for example, forces academics in South Africa to look hard at the fundamental knowledge that they teach, at its origins and continued relevance.

Diversity of student background also presents challenges simply in terms of ensuring that course material is accessible to all students, allowing full participation in the subject matter across the class. While students of engineering typically have high scores in their final school examinations, their experiences as learners, and indeed as young people from different
corners of the country, differ radically. There is no longer a ‘typical’ university student with a predictable background to plan around – the students come from myriad social and physical environments and with widely different experiences of life.

Within the Department of Civil Engineering at Stellenbosch University, Transport Science 324 and 364 are two third-year modules that form part of the compulsory curriculum of the BEng Civil Engineering degree. Transport Science 324 focuses on a theoretical understanding of transportation engineering and the correct application of transport science principles to related traffic engineering problems and transport planning projects. Transport Science 364 teaches the design principles and complexities related to the design of transport infrastructure.

Transport Science incorporates tangible theories and their real-world application, and so falls largely into the constructivist model of teaching, which considers knowledge to be developed by building on existing knowledge acquired through past experiences. In that sense, prior experiences have the potential to make learning easier, or more difficult. Throughout their lives students in these modules have been exposed to transportation - as users of the road network in vehicles (passengers and drivers), as pedestrians or cyclists, and as users of public transport. Teaching in Transport Science is enhanced by drawing on their prior experiences of transport, and by relating theory to everyday observations that students can make in their immediate environments.

This research aims to investigate whether this teaching model is fully effective in the Stellenbosch University context, and specifically whether differences in experience between students have the potential to influence their interest or performance levels in the subject. We wanted to determine if the constructivist model is indeed successful in engaging the majority of the students participating in Transport Science 324 and 364, and also whether particular groups with varying experiences of transport and traffic situations may be inadvertently disadvantaged by this approach.

**Cognitive and constructivist learning theories**

Theories of education accept almost universally that there are different but related types of learning, which together build comprehension and knowledge. Gottfredson (1997) conveniently pulled these types of learning together when he described learning as requiring an individual being able to “think abstractly, comprehend complex ideas, learn quickly and learn from experience”. Cognitive theories of learning are one family of theories that emphasise the mechanistic processes of thinking, pattern recognition, memorising and logical problem solving (Bayles, 1966; Letteri, 1985). Information is stored, processed (made sense of) and accessed through processes common to all people. Cognitive teaching strategies emphasize learning tactics – these can range from simple techniques such as note-taking, summarising, ordering of material and the use of mnemonics for memorising (e.g. Letteri, 1985), to the more demanding and ultimately empowering skills of self-regulation, creative/critical thinking and metacognition (Marzano, 1993; Pintrich, 2002). Cognitive learning techniques have in common the idea that such skills are needed to move knowledge from the realm of the physical world, to conscious, embedded knowledge. As Hoy, Davis and Anderman (2013) note, “The emphasis of the cognitive approach is on what is happening inside the head of the learner”.

Cognitive theories largely treat the learner as being uncontaminated by his or her history. The family of constructivist learning theories, in contrast, assumes that people construct their own knowledge; understanding and making sense of new knowledge rather than simply internalising it, and in so doing they draw on reservoirs of knowledge and experience they have stored already (Webb, 1980; Kolb, 2005). From the 1970’s onwards constructivist theorists have called on educators to reframe the process of education to reflect the evolution and prior experiences of the individual learner (Tomlinson, 1999).
Overall, constructivists believe that each learner interprets and understands the world largely through the filters of prior experiences and encounters, be they social, cultural or indeed purely educational. This makes sense. Who would not agree, for example, that a child’s educational background can play a significant difference in how literate or intellectually engaged he or she may be? Parents in many countries expose their children to a wide range of stimuli from birth, believing that such stimuli may enhance focus and intellectual capacity in their offspring. The growth in popularity of the ‘Mozart effect’ of music on spatial reasoning speaks to the shared understanding that exposure to stimuli has the potential to affect how a child performs intellectually in later years.

If the constructivist paradigm of learning is accepted, and given the context of shifting classroom demographics in South Africa, two challenges become clear. First, not much effort has been given to investigating the learning journeys of different and individual students in the university education system. If constructive learning theories are correct, each student interprets and understands new information (to some extent) against unique reference points. These reference points are assumed, most of the time, to be ‘background noise’, yet constructivists would have them play a far more significant role than our traditional educational methods would allow. Growing levels of diversity force us, secondly, to recognise the multiplicity of those reference points, and require that we make some effort to acknowledge their potential as shapers of understanding in the classroom.

Research objectives

Much of the Transport Science curriculum at Stellenbosch University is taught using constructivist principles, where knowledge of transport science is built on students’ actual experiences and everyday observations or traffic and transport environments. The degree of similarity of these experiences between students is generally assumed to be sufficiently high for common understandings and interpretations to emerge. Until now that assumption has been unchallenged.

Each year some students in the Transport Science modules perform particularly badly. Rather than just assuming that this is because ‘they do not work hard enough’ or that ‘they do not have the requisite learning skills’, which is what cognitive learning theorists might permit us to conclude, we were interested to investigate whether there were systemic reasons for their failure to thrive with this material. In particular, our concern was to investigate, through a constructivist lens, whether their experience in traffic/transportation in the past had influenced their interest and also their fundamental understanding of traffic relationships, and also whether our course contents had disadvantaged them through an unintended blindness to a different experience of traffic from what we had assumed to be common. These questions would be in line with the theories of cognitive development which suggests that an individual’s ability to learn is influenced directly by environmental influences that children are exposed to in key developmental stages (Warner & Sower, 2005; Salvia, Ysseldyke & Bolt, 2010).

In this study we were interested to see whether the transport experience of individual students in the class had any impact on their marks achievement in the module, which we assume to be a proxy for their understanding of the course material. We were particularly interested in looking at whether the dominance of private or public transport systems in their lives affected their academic performance in Transport modules. The interest in this topic was not simply academic – we wanted to ensure that all students in the Transport modules are able to engage with equal interest and a shared understanding of basic traffic concepts, in the subject matter.

Methodology

Students who had been enrolled in Transport Science 324 and 364 in 2018 were invited in January 2019 to complete an online survey with the aim of collecting information on their
various exposures to traffic situations in the past. These situations all have the potential to have positively or negatively influenced a young person's engagement in and knowledge of traffic issues.

The survey also required students to provide their student number. The student numbers allowed the research team to access study records, thus enabling a comparison between the academic performance of the students in the Transport Science modules with their academic performance in other modules. We had hoped that other background information such as home address may also allow us to investigate their academic performance in Transport Science based on differences between urban, rural and peri-urban traffic contexts, but there was insufficient information available for this to us to take this further.

In order to analyse the relationship between academic performance in Transport Science modules, students' marks for Transport Science modules were compared with a standardised measure of their exposure to private transport, public transport and their stated interest in Transport Science as a subject. The answers obtained from questions in the survey were allocated a number from 0 to 1, with higher values indicating greater experience of transport options. For example, for the question “When you were growing up, your family had access to a private car?”, answers were coded as: 0 for “No”, 0.5 for “Yes, some of the time” / “Only occasionally” and 1 for “Yes, all of the time”. This allowed a quantitative measure to be generated from a stated answer or qualitative measure. The results of the survey and student academic performance were analysed using a correlation matrix to determine which variables were correlated (using the correlation coefficient $R$). A linear regression analysis was conducted on correlated variables to determine the level of statistical significance (using the $p$-value) of this correlation. A $p$-value of less than 0.05 was assumed to indicate statistical significance, indicating a probability of less than 5% that the null hypothesis (no correlation) is rejected. The Scipy.stats programme was used to conduct the statistical analysis.

The survey responses were analysed to determine general information of the student population that took part in the survey, including students' access to and use of private transport modes, public transport and Non-Motorised Transport (NMT).

**Survey responses**

The survey resulted in 48 complete responses from a total of 92 civil engineering students enrolled for Transport Science 324 in 2018. A comparison between the demographics of the survey respondents and the full Transport Science 324 2018 class is presented in Table 1.

<table>
<thead>
<tr>
<th></th>
<th>Race</th>
<th>Gender</th>
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</thead>
<tbody>
<tr>
<td><strong>Survey Respondents</strong></td>
<td></td>
<td></td>
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<tr>
<td>White</td>
<td>73 %</td>
<td>Male</td>
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<tr>
<td>Black</td>
<td>13 %</td>
<td></td>
</tr>
<tr>
<td>Coloured</td>
<td>10 %</td>
<td>Female</td>
</tr>
<tr>
<td>Indian</td>
<td>4 %</td>
<td></td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Race</th>
<th>Gender</th>
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</thead>
<tbody>
<tr>
<td><strong>Transport 324 2018</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>White</td>
<td>70 %</td>
<td>Male</td>
</tr>
<tr>
<td>Black</td>
<td>16 %</td>
<td></td>
</tr>
<tr>
<td>Coloured</td>
<td>12 %</td>
<td>Female</td>
</tr>
<tr>
<td>Indian</td>
<td>2 %</td>
<td></td>
</tr>
</tbody>
</table>

The distribution of the race of survey respondents closely mirrors that of the Transport Science 324 class. Slightly more female students than anticipated answered the survey (35% of survey respondents compared to a population of 27% females in the Transport Science 324 2018 class).
The average marks obtained in Transport Science 324 for the Semester Mark (formative assessments conducted throughout the semester) and Final Mark (all assessments including examinations) of each of these groups are summarised in Table 2, and the results here indicate that the average marks of the survey respondents are very similar to the class averages. It is therefore reasonable to assume that the survey respondents provide a good representation of the population of 2018 Civil Engineering students.

Table 2: Academic performance of survey respondents

<table>
<thead>
<tr>
<th>Population</th>
<th>Assessment Type</th>
<th>Average Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Survey Respondents</td>
<td>Semester Mark Transport 324</td>
<td>66.0 %</td>
</tr>
<tr>
<td></td>
<td>Final Mark Transport 324</td>
<td>58.1 %</td>
</tr>
<tr>
<td>Transport 324 2018</td>
<td>Semester Mark Transport 324</td>
<td>64.4 %</td>
</tr>
<tr>
<td></td>
<td>Final Mark Transport 324</td>
<td>57.8 %</td>
</tr>
</tbody>
</table>

Analysis

Access to private motorised transport opportunities

The majority of respondents indicated that they have had regular access to private motorised transport. As can be seen in Figure 1, while growing up, 88% of the students studying Transport Science at Stellenbosch University had access to a private family car all of the time, 6% some of the time or occasionally, and 6% never.

![Figure 1: Access to private motorised transport opportunities](image)

In terms of current independence on the road, 62% of the respondents have their own car, 79% hold a driver’s licence and 85% of them can drive. Of the 15% of students that do not drive, 70% are from families that did not have permanent access to a family car while growing up.

Use of public transport

One out of every six respondents has never used public transport before. 83% have used some form of public transport (at least on a few occasions over the past seven years). 27% have either never used public transport, have only used an Uber type public transport service, or have only ever used public transport abroad. The public transport modes that have been used by most of the students at some point are Intercity bus services in South Africa and metro train in a South African city (used by a third of survey respondents). Only 29% of the sample have used a minibus taxi, 23% have used the Gautrain and 21% have travelled abroad and used train and bus systems in developed countries. Figure 2 illustrates...
the frequency with which all the modes of public transport that have been used. What is clear from this data is that the majority of our students are not regular public transport users, and many have not been exposed to the everyday forms of public transport in South Africa.

![Figure 2: Student usage of various modes of public transport](image)

**Influence of road experience on perceived understanding**

Transport Science

Survey respondents were asked if they feel that their own practical experience as a road user made the content the Transport Science Modules (324 and 364) more understandable. 73% of the respondents indicated that the modules reflected experiences that they had had and could understand. The remaining students thought that the modules contained some things to which they could relate to as a road user, but not completely. No student felt that their prior experiences had not been helpful at all.

<table>
<thead>
<tr>
<th>Duration of driving licence</th>
<th>Yes, experience useful</th>
<th>Experience only partially useful</th>
</tr>
</thead>
<tbody>
<tr>
<td>No licence</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>0-4 years</td>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>4 years +</td>
<td>11</td>
<td>4</td>
</tr>
</tbody>
</table>

We had anticipated that licenced drivers would be most likely to reflect most positively on the value of prior experience in their understanding of transport matters, and to some extent this is borne out in the results above, as 83% and 73% of the two populations of licenced drivers (the first group having held a licence of up to four years, the second group longer than four years) indicated a stronger view on the usefulness of past experience when compared with only 50% of the non-licenced-drivers. This suggests to us that experience of driving a vehicle advantages students learning about transport – possibly because of the driver education that precedes licencing, but also because their involvement with traffic and transport systems as a driver is arguably more personal and, of necessity.

**Influence of private transport experience on academic performance**

A measure (from 0 to 1) of how dominated a student’s life is by private, motorised transport (private transport engagement) was generated by taking the mean of this experience as determined by: availability of a private family car while growing up, whether motorised transport is used to get to class, whether the student has their own car and if a car is used to go home for holidays. This was compared with the mean of the student’s general academic...
performance (AP) and Transport Science academic performance (TP). It was found that private transport engagement correlated positively with TP ($p = 0.15$), indicating that TP increases with increased private transport engagement, and negatively with AP ($p = 0.16$). While these correlations themselves are not significant, a linear regression between private transport engagement and the difference in student performance between Transport Science and their general academic performance in other modules (TP – AP), is highly significant and strongly positively correlated ($p = 0.0003$), refer to Figure 3 below. This indicates that the difference between academic performance in Transport Science and general Civil Engineering modules increases with private motorised transport engagement. In other words, students perform better in Transport Science than would be predicted by their academic performance in other modules, as their exposure to private motorised transport increases.

**Figure 3: TP – AP performance versus private transport engagement**

In looking only at the relationship between holding a driver’s licence and academic performance in Transport Science there was a correlation here as well: drivers who had held their licence for four years or less showed higher marks in Transport Science than either students with no licence, or students’ with licences held longer than four years ($p = 0.05$). Although this latter seems like an anomaly it should be remembered that the older students in the class tend to be students who are repeating modules and hence may be weaker academically than some of the younger students.

**Influence of public transport experience on academic performance**

Experience of public transport modes was evaluated using the survey question “*In the past seven years you have used the following form of public transport: (please tick all that apply)*”. The more modes of public transport a student has used, the higher their annotated level of experience of public transport (allocated a measure from 0 to 1). In looking at the aggregated data, it was found that higher experience of public transport was associated with lower academic performance, both in general Civil Engineering modules ($p = 0.19$), and in Transport Science ($p = 0.04$), indicated in Figure 4. It is interesting to note that this relationship is significant in Transport Science, but not in general Civil Engineering academic performance, suggesting a more direct link between experience of transport (both private and public) and Transport Science academic achievement.

The relationship was confirmed when local public transport only was disaggregated from the data. Students who indicated that they use Metro Rail, local metro buses and minibus taxis also consistently performed more poorly in Civil Engineering and in Transport Science, than students who had never used public transport, or who had used public transport abroad, or nationally (refer to Figure 5). In Figure 5, the size of the bubble indicates the number of students that fall into the particular category (based on their experience of public transport). Students who had only used national public transport (long distance rail and long distance
bus) had the highest academic performance. More research is needed to make sense of the relationship between various types of public transport usage and academic performance. Causation has not been investigated in this research paper.

![Figure 4: TP versus exposure to public transport](image)

Conclusions

A constructivist learning theory suggests that learners interpret new information and build knowledge by drawing on prior experiences and encounters (which can be social, cultural or purely educational) rather than simply internalising new material. The Transport Science curriculum at Stellenbosch University, incorporating tangible theories, is implicitly based on constructivist principles as it relates theory to the experiences and everyday observations of the students' immediate and past environments. Inevitably, however, differences in experience and observations mean that there is potential for understandings of individual students, to differ from each other. Relying on the assumption of common experiences in past transport experience could thus create an imbalance in learning opportunities. This research aimed to investigate if this constructivist teaching and learning application is appropriate for the Stellenbosch University context and whether it is, in fact, successful in engaging the majority of the students participating in Transport Science.

The research showed clearly that students feel that their past experiences in traffic have indeed helped them to make sense of the material, and to understand the theories that underpin traffic behaviour. The analysis of their academic performance showed that there is
a clear and significant bias towards students with greater prior exposure to private motorised transport in terms of academic performance in Transport Science, and also to those who come to the class with a drivers licence obtained in the previous four years. Students with more experience of private transport are more likely to perform better in Transport Science than would be expected (based on their performance in other second year modules). Conversely, an increase in exposure to public transport is linked to poorer performance in both Transport Science and other Civil Engineering modules. Causality has yet to be investigated - this will be the subject of further research in the future. Both the students’ own opinions and the marks analysis confirm that the growth of traffic and transport knowledge is by nature, a constructivist process.

The fact that there is correlation between dominance of public transport and poorer academic performance in Transport modules highlights the need for us to find and develop ways of teaching that can address and correct this imbalance. The research has made us far more sensitive to the need to challenge our own assumptions about students’ experiences, especially if we rely on those to help illuminate the concepts. The module is, of course, focused very largely on the demands, patterns and needs of motorised transport, and only a relatively small portion of the Transport curriculum covers Non-motorised and public transport, so the bias within the material itself possibly advantages those with most exposure to private motorised transport. It is, of course, entirely possible that students with more experience in NMT and public transport have an advantage in understanding the theories relevant to these modes.

**Recommendations**

Our immediate focus is to explore ways of balancing students’ traffic experiences, as far as that is possible. We aim to develop a library of videos that the students’ can use to explore traffic scenarios in different contexts. We are committed to finding practical and safe ways of getting our students’ to engage directly with different traffic experiences – Virtual Reality technology may be a useful opportunity in this in the future. Our weekly practical and tutorial sessions will be critical to ensure that students’ gaps in experience are being recognised and addressed. There is value too, in incorporating more sharing of students’ experiences within the classroom – empowering the students’ to work on developing common understandings through more verbal engagement with the topics, and using methods of engagement with the students’ to draw out and share personal experiences. The research has reminded us sharply that the very different background of our students is something that we need to take into account in our curriculum planning.

The reasons behind the correlations shown in our research also need to be explored, and further research is being planned to understand the “why’s”; of our findings – why having a obtained a driver’s licence in the fairly recent past may advantage one student in this module, while using primarily public transport may have the adverse effect. There are some clear ideas about this, but we believe that research is necessary to explore this comprehensively.

**References**


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Abstract: In South Africa only about 40% of first-time entering Engineering cohorts complete their four-year degrees within five years. One of the goals of the National Benchmark Tests (NBTs) is to assist the South African higher education sector with diagnostic information to inform curriculum responsiveness. This study focuses on cohorts from the Engineering and Built Environment Faculty at a South African university. It uses One Way Analysis of Variance (ANOVA) as well as categorical methods to investigate the diagnostic potential of the NBTs within the Engineering and Built Environment. If Engineering faculties are to provide access, redress and success to the majority of students, they should ensure that curricula are responsive to the needs of students. The value of the diagnostic information has significant potential to enhance retention and success if used appropriately.

Introduction

In a study undertaken by the Council for Higher Education it was found that only 41% of the 2006 first-time entering South African Engineering cohort graduated within five years for a four-year degree (CHE, 2013).

The National Benchmark Tests (NBTs) (Griesel, 2006) assess the academic literacies of applicants to South African universities in three areas: Academic Literacy (AL), Quantitative Literacy (QL), and Mathematics (MAT). This paper investigates the diagnostic potential of the NBTs and argues that they can be employed to address low graduation rates by assisting to identify students who are not ‘Proficient’ and who need academic support and who would benefit from appropriate placement into extended university programmes.

Context

Retention and attrition in Engineering education is a problem the world over. A 2004 study of University of Colorado at Boulder’s College of Engineering and Applied Science found a graduation rate of 53% for engineering students (Gibbons, 2004, as cited in Knight et al). A 2009 study showed that the average graduation rate in OECD countries was 39%, while in Mexico and Turkey, the number stands at around 20% (ATTRACT).

Fisher (2011) calls for “multidimensional and multi-actor strategies” to address the Engineering throughput issue due to its complexity. Students are not only leaving university because they do not measure up academically. A number of authors who have studied this issue attribute this phenomenon and students’ decisions to leave engineering to both academic (e.g., curriculum difficulty, poor teaching and advising, and a lack of feedback and
support) and non-academic factors (lack of belonging in engineering, student stress, and unmet expectations) (May and Chubin, 2003). Marra et al (2012) state that underrepresented students experience a higher attrition rate than “majority” students, while Knight et al (2007) assert that less than 10% of Engineering students are lost to the system because they are struggling academically. These authors draw on Tinto, a theorist of higher education attrition, who proposed that the interaction of a student’s personal characteristics and their college or university experience determines whether a student completes his or her degree.

Unlike many studies of its kind, Bengesai and Paideya (2018) chose a quantitative rather than qualitative approach to determine factors that influence graduation. Their study demonstrates that those students who have financial advantages or academic advantages, such as having attended a reputable high school, or attending "Supplemental Instruction" are the most likely to graduate. These results echoed those of, for example, Pocock (2012), who found that 49% of the students who left their studies at the University of KwaZulu-Natal Engineering Faculty were facing financial difficulties.

The current authors addressed this issue in a previous study, which investigated the contributions made by the National Benchmark Tests and the National Senior Certificate in explaining performance in a four-year post-school qualification in Engineering at a traditional, public South African university. (Prince et al, 2017).

**Purpose**

The authors’ previous paper examined the predictive validity of the NBTs for Engineering study (Prince, Mutakwa, and Dunlop, 2017). In this paper, the tests’ diagnostic potential was investigated by posing the following question: “Given the low graduation rates, what is the diagnostic potential of the National Benchmark Tests of academic literacies for two cohorts of Engineering students at an institution of higher education?”

**Approach**

This study tracked two cohorts of Engineering students over four years and uses Analysis of Variance, Tukey’s Honest Significant Difference and Chi-square tests to assess the differences in academic standing at the end of the four years between and within the different performance groups in the NBT AL, QL and MAT. The study also uses categorical methods to illustrate the full profiles of students by the three different academic standing categories.

**Analysis of Variance**

Analysis of Variance is a statistical technique used to assess if the mean of a given variable is statistically different across three or more independent groups. There are many forms of analysis of variance. In this study, we use the One-Way Analysis of Variance to assess if there were significant differences on performance in the AL, QL and MAT NBTs across the three academic standing groups.

**Tukey’s Honest Significant Test**

Although the ANOVA can show if there are significant differences between given independent groups, it does not specify which independent groups are significantly different from the other. To address this, we use the Tukey’s Honest Significant difference Test. This test compares the mean of the independent variable group against the means of the other groups and determines whether there is a statistically significant difference between them.

**Academic Standing**

Academic Standing refers to the outcome at the end of minimum time of study of a degree program. In this study, the focus is on professional engineering degree programmes which
take a minimum of four years to complete. The end of four-year outcomes were grouped into three distinct categories, i.e. QUAL, CONT and FAIL. QUAL refers to students who met all the requirements of their study and could graduate. CONT means the student is yet to complete the requirements to graduate and they are continuing with their studies. FAIL means those student who failed or who left before qualifying. Table 1 shows the distribution of the academic standing for the sample used in this study.

As can be seen from Table 1, under half (45.1%) of first-time entering students graduated in minimum time, nearly 40% were still studying, and about 15% had dropped out.

Table 1: Overall Academic Standing

<table>
<thead>
<tr>
<th>Academic Standing</th>
<th>N</th>
<th>Percent (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>FAIL</td>
<td>106</td>
<td>15.2</td>
</tr>
<tr>
<td>CONT</td>
<td>277</td>
<td>39.7</td>
</tr>
<tr>
<td>QUAL</td>
<td>314</td>
<td>45.1</td>
</tr>
<tr>
<td>Total</td>
<td>697</td>
<td>100</td>
</tr>
</tbody>
</table>

Results

This section presents the results of the analysis conducted for this study. The study focused on two cohorts of students who were enrolled for a four-year engineering degree. The self-reported demographic information of the sample is summarised in Table 2.

As can be seen from Table 2, more than three-quarters (77.04%) are male and the largest population group is White (38.45%) followed by Black (29.84%).

Table 2: Demographics

<table>
<thead>
<tr>
<th>Gender</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>160</td>
<td>22.96</td>
</tr>
<tr>
<td>Male</td>
<td>537</td>
<td>77.04</td>
</tr>
<tr>
<td>Total</td>
<td>697</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Population Group</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>208</td>
<td>29.84</td>
</tr>
<tr>
<td>Chinese</td>
<td>15</td>
<td>2.15</td>
</tr>
<tr>
<td>Coloured</td>
<td>64</td>
<td>9.18</td>
</tr>
<tr>
<td>Indian</td>
<td>78</td>
<td>11.19</td>
</tr>
<tr>
<td>Unknown</td>
<td>64</td>
<td>9.18</td>
</tr>
<tr>
<td>White</td>
<td>268</td>
<td>38.45</td>
</tr>
<tr>
<td>Total</td>
<td>697</td>
<td>100</td>
</tr>
</tbody>
</table>

Comparison of NBT means by academic standing groups

This section focuses on comparing the mean scores of the three NBT literacies across the three academic standing groups. The results are grouped by NBT domain. The first section
under each domain shows the means and confidence intervals, followed by an ANOVA and Tukey’s Honest Significance Difference test. The last section of the results shows a categorical visualisation of the performance on NBTs and Academic Standing.

**Academic Literacy**

Figure 1 shows that students who qualified in minimum time had the highest mean score at 73.8% in Academic Literacy followed by the students who were continuing with their studies with a mean of 69.7%. The students who failed had the lowest mean score of 62.2% in Academic Literacy.

![Academic Literacy Performance by Year 4 Academic Standing](image)

**Figure 1: Confidence Interval: Academic Literacy by Year 4 Academic Standing**

**Analysis of variance and Tukey's Honest Significant Test**

A one-way ANOVA was conducted to determine if Academic Literacy (AL) was different for groups with different Academic Standing (AS) codes. The data is presented as a mean and ± standard error. Participants were classified into three groups: Fail (FAIL) \( (n = 106) \), Continue (CONT) \( (n = 277) \) and Qualify (QUAL) \( (n = 314) \). There was a statistically significant difference between all three groups as determined by one-way ANOVA \( (F(2,694) = 49.08, p <0.001) \). A Tukey post-hoc test revealed that Academic Standing was statistically significantly higher in the Qualify group compared to the Failure group \( (8.99 \pm 0.44 \text{ AL, } p <0.001) \) and the Qualify group compared to the Continuing group \( (3.20 \pm 0.32 \text{ AL, } p <0.001) \) as well as the Continuing group compared to the Failure group \( (5.79 \pm 0.47 \text{ AL, } p <0.001) \).

**Quantitative Literacy**

Figure 2 shows that students who qualified had a higher mean score at 78.4% compared to those with other academic standing grades. This pattern suggests that a higher score in Quantitative Literacy is correlated with graduating in minimum time.
Analysis of variance and Tukey's Honest Significant Test

A one-way ANOVA was conducted to determine if Quantitative Literacy (QL) was different for groups with different Academic Standing (AS) codes. The data is presented as a mean and ± standard error. Participants were classified into three groups: Fail (FAIL) \(n = 106\), Continue (CONT) \(n = 277\) and Qualify QUAL \(n = 314\). There was a statistically significant difference between all three groups as determined by one-way ANOVA \(F(2,694) = 59.42, p < 0.001\). A Tukey post-hoc test revealed that Academic Standing was statistically significantly higher in the Qualify group compared to the Failure group \(8.74 ± 0.63\) QL, \(p < 0.001\) and the Qualify group compared to the Continuing group \(3.48 ± 0.45\) QL, \(p < 0.001\) as well as the Continuing group compared to the Failure group \(5.26 ± 0.67\) QL, \(p < 0.001\).

NBT Mathematics

Figure 3 shows that students who qualified had a higher mean score at 71.0% compared to those with other academic standing grades. This pattern suggests that a higher score in Mathematics is correlated with graduating in minimum time.
Analysis of variance and Tukey’s Honest Significant Test

A one-way ANOVA was conducted to determine if Mathematics (MAT) was different for groups with different Academic Standing (AS) codes. The data is presented as a mean and ± standard error. Participants were classified into three groups: Fail (FAIL) \((n = 106)\), Continue (CONT) \((n = 277)\) and Qualify (QUAL) \((n = 314)\). There was a statistically significant difference between all three groups as determined by one-way ANOVA \((F(2,694) = 63.99, p <0.001)\). A Tukey post-hoc test revealed that Academic Standing was statistically significantly higher in the Qualify group compared to the Failure group \((7.03 \pm 0.70 \text{ MAT}, p <0.001)\) and the Qualify group compared to the Continuing group \((2.19 \pm 0.50 \text{ MAT}, p <0.001)\) as well as the Continuing group compared to the Failure group \((4.84 \pm 0.73 \text{ MAT}, p <0.001)\).

Mosaic Plots

Figure 4 summarises the categorical distribution of the NBT performance and Academic Standing. The NBT performance was categorised as Proficient and Not Proficient. Not Proficient referred to intermediate and basic proficiency levels on NBT performance. The results show that the students who obtain a proficient score in each of the three NBTs have the highest chance of qualifying in minimum time and, if they do not, of continuing their studies and the least chance of failing. Students who obtain a non-proficient score in each of the three NBTs have the highest chance of failing and, if they do not fail, then of continuing their studies and the least chance of qualifying. Overall, the NBTs show that students who do not obtain a proficient score in the three NBTs need academic support to increase their chance of completing their degrees in minimum time or of continuing with their studies.
Figure 4: Mosaic Plots: Year 4 Academic Standing by NBT AL, QL & MAT Proficient and Not Proficient

Conclusions

The results indicated that there are statistically significant differences between the performances of students in the assessed literacies. Students who had high scores in the Academic Literacies also had the highest chance of qualifying in minimum time. Performance on the NBTs can be used to identify students at risk as well as point to the teaching and learning and curriculum development interventions that need to be put in place.

This study has demonstrated the potential of the NBTs to provide diagnostic information, which can be used to improve student retention and success. The NBT results can be applied to ensure that student preparedness is addressed through appropriate teaching and learning strategies. The NBTs also provide subdomain information which can enable lecturers and tutors to focus on particular aspects of the academic literacies, Academic Literacy, Quantitative Literacy and/or Mathematics, in the classroom.

The NBT results can also be taken into account during the university admissions stage to examine levels of student preparedness and ensure that applicants are appropriately placed, for example, on mainstream programmes, foundation courses, or augmented instruction programmes. The subdomain information can then be used in these latter programmes to address students' academic needs.

The South African Engineering Education system cannot only provide access to students and then fail most students. The system should be providing epistemological access - access to knowledge – to students by taking their academic literacies into account and responding to these by adapting teaching and learning practices and through the development of appropriate curricula.

While this study has focused on the diagnostic potential of the NBTs in ensuring throughput of South African Engineering mainstream students, further studies could be conducted on the application of these results on the graduation rates of those students in mainstream versus extended degree programmes.

References


Acknowledgements

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An interrogation of the relationship between theoretical concepts and their application in practice in the curriculum of a professionally orientated higher education programme in South Africa

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Abstract: The research presented in this paper is a work in progress study towards a Masters in Education degree that will focus on how knowledge is represented in a professionally orientated Diploma programme in Sound Engineering. This programme is intended to produce graduates who are workplace ready sound engineers for the local and international audio industry. It has been observed in this programme that many students are able to develop working procedures that are tied very closely to the context of a particular practical task, but appear unable to adapt these procedures to a different or unfamiliar context. It is suspected that students are rote-learning procedures in order to complete tasks, but are not accessing the theoretical knowledge that underpin these procedures. This research aims to reveal how theoretical knowledge is represented in the curriculum documentation, and how this theory is linked to its application in practice.

Introduction

Education in South Africa has been prioritised by the post-apartheid government as one of the most important areas of redress. In July 2003 Nelson Mandela stated “It is one of our major tasks of reconstruction to build an education system that provides quality opportunities for all our people. It is fundamentally important that our children are prepared to compete with confidence in the international arena” (Mandela, 2003). In light of this, educational programmes that prepare South Africans for employment in economically viable local industries are a fertile ground for research in education. The research presented in this paper will explore how knowledge is packaged in the curriculum of a South African educational programme designed to prepare graduates for employment within the audio industry with a specific focus on sound engineering.

Context

Cape Audio College – The Institute of Sound Technology, is a private higher education provider located in Cape Town, South Africa that specialises in training sound engineers and music producers for various job types in the local and international audio industry. This field is both highly technical and creative in nature and the training comprises theory lectures as well as extensive practical training. The Institute also utilises a variety of guest lecturers, and industry professionals in the development and delivery of the curriculums.

Cape Audio College was founded in 1995 after the owner recognised a lack of formalised training in the field of sound engineering in South Africa. He based the original curriculum on the experiences of his own training as a sound engineer in a private vocational college in Australia. Over the last 24 years the structures of the College and the programmes on offer have developed and changed. There are currently two main programmes on offer, the NQF level 6 Diploma in Sound Technology and Production (DSTP) and the NQF level 5 Higher Certificate in Sound Technology, both of which are Registered with the Department of Higher Education and Training (DHET) and accredited by the Council on Higher Education (CHE). The designs of these two programmes have a strong vocational focus to appropriately prepare students for the working industry.
There have been two main driving forces behind the design and structure of these programmes. Firstly, the needs of the audio industry in South Africa, whose values are communicated through an Academic Advisory board, made up of local industry professionals, and the College staff. This is an extremely important aspect of the development of the learning programmes as they are primarily designed to develop employable graduates for a niche industry. The second driving force are the requirements necessary for registration with the DHET and accreditation by the CHE. Private higher education providers in South Africa must be registered with the DHET and have their programmes vetted and accredited by the CHE in order to legally operate. This is part of a drive for national regulation of higher educational offerings in South Africa to ensure they are working towards the needs of the post-apartheid economy. There has been some tension between the values required by these statutory bodies and those held by the audio industry, with the programme design process attempting to meet as closely as possible the requirements of both of these driving forces.

The debates around the purposes of higher education are currently of particular focus in South Africa with the call for decolonisation of curricula in the academies. Additional contestations include concerns around, “curricula for employability versus ‘educating the mind’, vocational versus academic, knowing versus being” (Shay, 2014). Diploma curricula are typically characterised as being practical in their nature with a primarily vocational focus, and yet containing some theoretical knowledge (Shay, 2016). This links to the primary rationale behind offering a Diploma programme in Sound Engineering, as this type of qualification is felt to be more suited to the audio industry. However, feedback from the audio industry has indicated challenges in Diploma graduate’s abilities to adapt their understanding to a different or unfamiliar context.

The theoretical framework for this research is informed by the Social Realism paradigm. This paradigm was developed out of an exploration into how the Critical Realist philosophy could be adapted into a sociological framework and applied to knowledge and education practices (Moore, R. 2013). Legitimation Code Theory (LCT) – Semantics, as theorised by Karl Maton, will form the primary analytical tool that will be operationalized in this research (Maton, 2014). LCT semantics deals with the context dependency of meaning (semantic gravity), and the condensation or complexity of meaning (semantic density). Suellen Shay utilised LCT semantics in her 2016 publication ‘Curriculum at the Boundaries’ where she identified that curricula with professional or vocational modalities, like diploma programmes, tend to exhibit both strong semantic gravity and strong semantic density (Shay, 2016). As such the DSTP programme is expected to provide an interesting context within which to explore how theoretical knowledge is packaged in a Diploma curriculum within the sound engineering field.

Research Questions

The questions this research aims to address are as follows:

To what extent do the assessment designs of three modules in the Cape Audio College Diploma in Sound Technology and Production (DSTP) programme enable or constrain the links between theoretical knowledge and its application in practice?

Sub Questions

- What traces of linking theory to its context of application in practice are evident in the practical assessments in the 1st, 2nd and 3rd years of DSTP programme?
- How are the complexity of theoretical concepts presented in the assessments in the 1st, 2nd and 3rd years of the DSTP programme?
Rationale

The rationale behind the research questions above stems from the observation that many students enrolled in the DSTP programme are able to develop working processes and procedures that are tied very closely to the context of a particular practical task, but often appear unable to adapt these processes and procedures to a different or unfamiliar context. This changing context may be anything from a different piece of equipment, a different musical genre or instrument, or any variation in the practical environment. These same students are generally observed to perform adequately in clearly prescribed practical tasks but often do not perform well in theory tests, suggesting a disconnect between how these students engage with the practical and theory content.

When completing practical tasks and assignments, students are expected to be making decisions informed by their understating of the theoretical concepts covered in the lectures. These theoretical concepts relate to the physics of sound, the physiology of the human hearing system, and the technologies used to capture, process and reproduce sound. When presented with a practical task, a sound engineer must assess the particular needs of the project and make decisions about which equipment, processes and procedures will best meet the needs of the project. Effective sound engineers should be able to refer to their understanding of the theoretical concepts listed above in order to guide and justify the practical decisions and actions taken. Observations from within the industry seem to show that students are not necessarily engaging with the theoretical concepts in a way that enables them to make informed and rationalised decisions as to how they will approach a task when presented with changing practical contexts.

The DSTP programme at Cape Audio College is a higher education qualification; however, as mentioned above, it is firmly rooted in training students for the profession. Theoretical concepts are therefore presented quite differently in this context compared to that in universities. Universities generally focus on theoretical concepts abstracted from a specific context of application whereas professionally orientated educational offerings, like the DSTP programme at Cape Audio College, generally attempt to present theoretical concepts with a very strong link to its context of application. This research is expected to demonstrate that an interrogation of the linking between theory and its practical application, as well as the complexity of theoretical concepts in the assessment documents of the DSTP programme, will help to provide an understanding of how theoretical knowledge is treated and taught by educators in this specific context.

Theoretical Framework

Social Realism recognises that reality exists independent of people, but that knowledge is socially produced. “Knowledge is historically produced through collective procedures within which critique is a constitutive principle” (Moore, 2013, p. 16); and this need to critique knowledge sets Social Realism apart from more traditionalist views that knowledge is beyond question. In the Social Realism paradigm, effective research must be informed and guided by a firm theoretical stance.

Basil Bernstein, a theorist in the sociology of knowledge developed a theoretical model that he called the Pedagogic Device. This is a model that can be used to analyse the process by which knowledge is converted into a working curriculum. Bernstein identified three fields within the pedagogic device, namely: the field of production, where knowledge is produced; the field of recontextualisation, where knowledge is transformed into a curriculum; and the field of reproduction, where the curriculum is brought into the classroom and appropriated by teachers (Bernstein in Singh, 2002). This research is seated in the field of recontextualisation, as it is the curriculum of the DSTP programme, and more specifically the assessment documents, that will be the central focus of the research.

It is worth mentioning that sound engineering does not have an extensive and established canon of knowledge to draw on like many of the more traditional disciplines; knowledge is
rather produced in the field of practice. As such, the curricula that have been developed by different institutes can look significantly different from one another, as they are based on what knowledge has been prioritised. There are some established textbooks in the field; however, the educators at Cape Audio College have developed, and continue to develop the DSTP course notes and curriculum themselves. The educators at Cape Audio College are professional sound engineers who have been drawn to teaching; the field of reproduction therefore looks fairly different to the traditional academic environments of a university. The lecturers deliver the content of the curriculum with a focus on the real-world application of this content, teaching in order to prepare the students for the workplace.

Bernstein also developed the concepts of horizontal and vertical forms of discourse, of which, “‘Horizontal discourse’ refers to everyday or ‘commonsense’ knowledge and ‘entails a set of strategies which are local, segmentally organised, context specific and dependent’” (Bernstein in Maton, 2014 p. 2). Vertical discourse, in contrast, refers to educational knowledge more abstracted from the context of application, and symbolically represented. In both of these discourses, access to meaning is reliant on an understanding of the symbolically condensed meanings expressed within them. Karl Maton (Maton, 2014), however, felt that Bernstein’s discourses offered a binary perspective of educational knowledge. He suggested that viewing knowledge and how it relates to context, as well as the condensation of meaning in theoretical concepts, as existing on continua would be a more beneficial approach. Maton’s Legitimating Code Theory (LCT) – Semantics was developed as a way of achieving this.

The Semantics aspect of Maton’s LCT will form the main theoretical framework within which this research is seated. Semantic gravity refers to the degree to which meaning relates to context; the stronger the semantic gravity (SG+) the closer meaning is related to context, and the weaker the semantic gravity (SG-) the further meaning is abstracted from context (Maton, 2014). Context in this research is defined as the context of application in the professional workplace, rather than the context of the classroom i.e. a student using their understanding of theoretical concepts in order to inform the decisions that they make in the recording studio. Maton’s concept of a continuum of proximity and abstraction to meaning from context provides a more inclusive framework for analysing knowledge practices (Maton, 2014).

Since Maton views semantic gravity on a continuum, semantic gravity can be strengthened by taking abstract ideas and concretising them through contextually driven examples. Similarly, one can weaken semantic gravity by abstracting from the concrete particulars of a specific context (Maton, 2014). Traditional university disciplines justify teaching abstracted knowledge because the students are learning knowledge that is transferable beyond the learning context; however, vocational training is routed firmly in training for a particular context, without the knowledge necessarily being transferable to other contexts. There has been some critique that this leads to graduates who are only employable within a very narrow field.

Maton’s concept of semantic density relates to the degree of condensation of meaning within symbols in knowledge practices. Like semantic gravity, Maton developed semantic density as a way to elaborate on Bernstein’s earlier theorising. Bernstein’s concepts of horizontal and vertical discourses, as described above, were further elaborated to distinguish two knowledge structures within the vertical discourse, namely horizontal and hierarchical knowledge structures (Maton, 2014).

Horizontal knowledge structures are characterised as “a series of specialised languages each with its own specialised modes of interrogation and specialised criteria… with non-comparable principles of description based on different, often opposed, assumption” (Bernstein, 1996, p. 172-173, in Maton, 2014, p. 68). This knowledge structure is usually exemplified in the structures of the varied disciplines in humanities departments, and it develops through the proliferation of segmented and strongly bounded languages (Maton, 2014). Bernstein described hierarchical knowledge structures as “an explicit, coherent,
systematically principled and hierarchical organisation of Knowledge” (Bernstein, 1996, p. 172-173, in Maton, 2014, p. 69). This knowledge structure develops through vertical abstractions and increasing generalisations, and is usually exemplified by the sciences.

Muller termed the key differences between hierarchical and horizontal knowledge structures as ‘verticality’ and ‘grammaticality’, where verticality refers to the “relations among ideas within hierarchical knowledge structures” (Bernstein, 2000, p. 161, in Maton, 2014, p. 3). Verticality here is referring to the integration of ideas through vertical abstraction, and the relations between concepts within the knowledge structure. Grammaticality, in contrast, refers to relationship between ideas and their external subjects. Building on these concepts, Maton developed his concept of semantic density as a way to interrogate the condensation of meaning within theoretical concepts, terms and phrases. As such, strong semantic density refers to a range of meanings or lengthy descriptions that are condensed into symbols that can be used to represent them. Weak semantic density therefore refers to meanings and concepts that are explicit and all the constituent parts are exposed.

As with semantic gravity the strength of semantic density varies on a continuum from weaker semantic density (SD-) to stronger semantic density (SD+) (Maton, 2014). As such, semantic density may be strengthened along this continuum by condensing a range of meanings into succinct symbols, or weakened by unpacking and representing all the constituent parts of a symbol. Maton claims that this provides a far more inclusive way of viewing knowledge practices than the binary characteristics put forward by Bernstein.

Together, semantic gravity and semantic density provide two independent, yet interrelated continua of strengths against which knowledge practices can be interrogated. In this research these continua are expected to provide a perspective as to how theoretical concepts are presented in the assessment documents of DSTP programme, both in terms the condensation of meaning, as well as the proximity of these theoretical concepts to the context of application. The LCT semantics continua may be represented as the axes of a Cartesian plane (see Fig 1 below) that can be used to represent the specific semantic characteristics of a particular knowledge practice at a moment in time, or to plot how these practices develop and change over time. It is the movements up and down these continua that enable or constrain engagement with knowledge represented in a curriculum (Maton, 2014).

Fig 1: Semantic Codes of Legitimation (Maton, K. 2011: 66)

The research will focus on data from within the field of recontextualisation portion of Bernstein’s pedagogic device, as it is the curriculum design of the educational programme that will be interrogated (Bernstein in Singh, 2002). The choice to focus on this area of the pedagogic device is motivated by the fact that the DSTP curriculum was developed directly from the profession rather than from an established canon of knowledge. Research into the field of recontextualisation should provide a valuable perspective as to how theoretical concepts are treated in the DSTP programme.
This research aims to interrogate the linking between theoretical knowledge and its application in practice in the first year Audio Technology Fundamentals 1 (ATF1), the second year Music Production 2 (MP2), and the third year Music Production 3 (MP3) modules in the DSTP programme. The research should provide an understanding of whether the assessment documents help to promote or restrict the linking of theoretical concepts to their application in practice. Further, the condensation of meaning will be explored in order to uncover the forms that theoretical concepts take in this programme, as well as the trajectory of how theoretical knowledge is assessed through the DSTP programme. Karl Maton’s concepts of semantic gravity and semantic density will form the basis of the interrogation and will be used to map the semantic characteristics of the knowledge practices represented in these modules.

**Methodology**

**Data Sources**

This research focuses on the assessment documents from three modules in the DSTP programme as the primary sources of data. The assessment documents take the form of a practical assessment brief from each of the three modules, which are given to the students when beginning an assessment. These documents contain the following information relevant to this research: the learning outcomes, the assessment criteria, the assessment outline, and the assessment marking rubric.

The assessment briefs provide information regarding the actions a student must take to complete the assessment tasks, and the marking rubric provides an indication of what is prioritised in terms of the mark allocations. These documents provide a direct platform through which the expectations of how the students are expected to engage with the theoretical concepts are communicated.

**Analysis**

This research will interrogate the linking between theoretical knowledge and its application in practical assignments in the DSTP programme in terms of Karl Maton’s concepts of semantic gravity. The condensation of theoretical concepts and how this condensation changes through each year of the DSTP programme will be explored through semantic density. As such, two levels of analysis will be used to plot theoretical knowledge within the curriculum. The findings from these analyses will then be plotted on a semantic Cartesian plane for final analysis.

To apply Maton’s semantics concepts to the research data, they must be operationalized in order to design valid research tools. In this research, strong and weak Semantic Gravity has been aligned with the attributes of educational learning objectives in terms of their levels of specificity as modelled in Bloom’s Taxonomy (Bloom, 1956). This alignment was chosen as a way to operationalize semantic gravity for analysis of these specific curriculum texts because Bloom’s taxonomy provides established markers for identifying the learning objectives expected from a curriculum document. When aligned with Semantic gravity, this provides a framework through which the linking between theory and practice can be assessed.

Bloom modelled six levels of educational learning objectives that can be used to guide curriculum and assessments in terms of the goals of these educational systems. Bloom states that “Use of the taxonomy can also help one gain a perspective on the emphasis given to certain behaviours by a particular set of educational plans” (Bloom, 1956, p. 2). The six levels of educational objectives in Bloom’s taxonomy (Bloom, 1956) are as follows:

**Knowledge:** This objective involves a student demonstrating the ability to remember, recall, identify or list educational content.

**Comprehension:** This objective involves a student demonstrating the ability to understand, explain or illustrate educational content.
**Application**: This objective involves a student demonstrating the ability to apply, use or demonstrate educational content.

**Analysis**: This objective involves a student demonstrating the ability to compare, contrast or classify educational content.

**Synthesis**: This objective involves a student demonstrating the ability to plan, create or design based on the educational content. This requires linking concepts together.

**Evaluation**: This objective involves the ability to judge, relate, evaluate or compare educational content.

The Knowledge, Comprehension and Analysis learning objectives of Bloom’s Taxonomy have been classified as being associated with weak semantic gravity (SG-) in this research, in contrast to the more traditional application of this taxonomy. This is because achievement of these learning objectives in the Assignments under evaluation in this research are thought to illustrate an understanding of theory abstracted from the context of application. For example, when asked to define a particular concept, this does not necessarily involve linking this concept to its application.

The Application, Synthesis and Evaluation learning objectives from Bloom’s Taxonomy have been classified as being associated with strong semantic gravity (SG+), due to the fact that achievement of these learning objectives is thought to illustrate the application or understanding of theory in a practical context. These outcomes illustrate a specialising of general theory to a specific application, a strengthening of semantic gravity in application. In the assessments under evaluation in this research, the application of theory in practice requires a student to make specific contextual decisions as to how to apply the theory at hand. To make an evaluation about the practical approach required to record an instrument for example, is directly dependent on the specific context.

The outcomes illustrated in Blooms Taxonomy are traditionally considered to deal with meaning closely linked to context at the Knowledge and Comprehension levels and the Synthesis and Evaluation levels to deal with meaning abstracted from context. This is due to the fact that in most traditionally academic fields, complexity lies within the theory of that field and thus abstraction from context requires the levels of cognition expected with the Synthesis and Evaluation outcomes. In the proposed analysis, the levels of Bloom’s taxonomy have been coded the other way around, with Knowledge and Comprehension being coded to represent weak semantic gravity and therefore an abstraction from context. The Synthesis and Evaluation levels have been coded with strong semantic gravity and therefore a close proximity to context. These designations have been coded this way because in sound engineering the complexity of the field lies not in the theory, but rather in the context of application. This is where the more complex judgments must be made and thus it is in the contextual application of theory where the levels of cognition expected with the Synthesis and Evaluation outcomes are required. Demonstrating Knowledge or Understanding rarely involves linking to context.

Strong and weak Semantic Density have similarly been aligned with the Structure of Observed Learning Outcomes (SOLO) taxonomy modelled by John Biggs (Biggs, 1982). This alignment was chosen as Biggs’ SOLO taxonomy is a means of classifying learning outcomes in terms of their complexity, and therefore links into the concept of Semantic Density as defined above.

Biggs’ SOLO Taxonomy (Biggs, 1982) models five levels relating to the complexity of understanding as follows:

**Pre-Structural**: the student is unable to demonstrate understating of any concepts.

**Uni-structural**: the student is expected to demonstrate understanding of a single relevant aspect of a concept.
Multi-structural: The student is expected to demonstrate an understanding of several relevant aspects, but independently without relating to each other.

Relational: The student is expected to demonstrate an understanding of several relevant aspects, and to be able to integrate them into a coherent whole.

Extended abstract: The student is expected to be able to demonstrate an understanding of several relevant aspects, integrate them into a coherent whole, and extrapolate this to a new context or application.

This research will focus on the latter four levels of the taxonomy as the data being analysed consists of assessment briefs rather than assessment submissions where the pre-structural level could present. The Uni-structural and Multi-structural levels are coded as exhibiting weaker Semantic Density (SD-) as concepts here are not complex or interrelated, and therefore demonstrate a low level of condensation of meaning. For example, a learning outcome on an assessment brief that expects a student to demonstrate an understanding of a concept without linking to others would exhibit weak semantic density. The Relational and Extended Abstract levels are coded as exhibiting stronger Semantic Density as these concepts indicate a higher level of condensation of meaning. Learning outcomes that require a student to demonstrate advanced understanding of multiple concepts that must be applied in a new context would exhibit a strengthening of semantic density. The Learning outcomes and assessment criteria from the data will be analysed in terms of these levels of complexity as it is in the application of theoretical knowledge in practice that proficiency is assessed in the DSTP programme.

Findings

This paper reflects work in progress research, where a pilot study was conducted focussing on a first-year practical assessment that was analysed against semantic gravity as explained above. This assessment involves students completing procedural tasks using hardware equipment and software in a recording studio for the purposes of recording an acoustic instrument. In the pilot study it was revealed that the learning outcomes expressed on the assessment brief exhibited a relatively weak semantic gravity as they do not contain much to link them to their contextual application. They indicate what knowledge students should have an understanding of, but not the specific contextual application of this knowledge for the purposes of the assessment. This is not unexpected as learning outcomes are usually closely related to the theory and knowledge that inform practice.

The assessment criteria associated with the learning outcomes in the assessment brief are where one would expect to see the link to contextual application becoming clear. These assessment criteria indicate specifically what the marker will be evaluating in the recordings submitted by the students. Interestingly the majority of the assessment criteria demonstrate a relatively weak semantic gravity, with only two criteria exhibiting a link to the context of application. They generally refer to the theoretical concepts informing the practical actions taken but provide little-to-no explicit linking of these concepts to their application in practice. The assessment outline in contrast, exhibits in its entirety, a relatively strong semantic gravity. Here the concepts indicated in the learning outcomes and assessment criteria are broken down into a highly detailed step-by-step breakdown of their application in practice. This level of detail is appropriate and expected in a first-year assessment. The weighting on the marking rubric also demonstrates that the majority of the marks are allocated to the practical demonstration of concepts and therefore a strong semantic gravity.

This pilot study has exhibited that the operationalization of semantic gravity for analysis of the data in this research is effective, and that the use of the analytical tool through the remainder of the data should reveal a trajectory of semantic gravity through the 3 years of the curriculum. Due to the vocational nature of the DSTP programme, one would expect to see a strengthening of semantic gravity through the programme, with the exit summative
assessments briefs exhibiting the closest linking of theoretical knowledge to its context of application.

Although the pilot study did not include semantic density in the analysis, the development of the theoretical framework above did involve some preliminary analysis of the data with respect to semantic density. This analysis focussed primarily on the learning outcomes and assessment criteria of the three assessment briefs. This revealed that although there is evidence of strengthening of semantic density through the three years of the programme, this could lead to the specific knowledge that should be accessible, actually becoming more and more invisible to the student. The act of condensing theoretical knowledge into learning outcomes and assessment criteria involved increasingly more condensation through the programme. Coupled with this was an observation that the specific theoretical knowledge that should be accessed, actually appeared to become increasingly more invisible. This is contrary to the rationale behind providing learning outcomes and assessment criteria on assessment briefs. They are expected to make clear to the students what knowledge they should be accessing, and will be assessed upon. This research is expected to reveal that this approach can in fact have the opposite outcome.

If evaluated in terms of vocational education, however, this may have the benefit of helping to prepare graduates for the working industry where linking to the theoretical knowledge that should be accessed is never made explicit in client or project briefings. If the progressive condensation of meaning (semantic density) and context dependency of theoretical knowledge (semantic gravity) through a vocationally orientated programme is foregrounded in curriculum design, and students are guided effectively through this programme, these factors could be used to enhance graduate success. Further, this approach could help to contribute to the goal of transformative education in South Africa by foregrounding knowledge practices, in addition to skills development in vocationally orientated engineering education programmes, with the purpose of producing industry ready and employable graduates for the local and international markets.

Recommendations

The completion of the research project presented here is expected to reveal how theoretical knowledge is presented in the curriculum documentation of the DSTP programme at Cape Audio College and should also contribute an additional framework for analysis of knowledge practices in educational programmes in general. It is recommended that further research into knowledge practices in professional and vocationally orientated programmes in engineering education will provided greater insight into these findings. A focus on how this specific framework can be applied practically in curriculum design, is expected to help improve graduate preparedness and contribute to the South African transformative education agenda.

References


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An exploration of first year engineering students’ perception of the university’s responsibilities

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Abstract: Given the various roles of universities to advance disciplinary knowledge, inculcate social awareness in students, and produce work-ready graduates, this paper explores first year engineering students’ perceptions of the university’s responsibilities towards them. Interview data were collected from 38 first year chemical engineering students at two different South African universities. A preliminary data analysis suggests that a majority of students expected the university to provide them with academic support, which includes a work-ready education. Additionally, several students expected the university to provide adequate residences, meals, and mental health facilities. In light of the recent #FeesMustFall protests, expectations regarding safety were also noted. Finally, there were some traces of managerialism in students’ expectation in that a few students expected the university to provide them with their money worth, and on the other a few others critiqued the business-like functioning of the university that values financial gains over student learning.

Introduction

The changes in the economic order with the advent of globalization have had an impact on the role of universities. While the purposes of higher education vary across countries, one of the major responsibilities that universities in current times have is to produce skilled graduates, and thus, at least theoretically, contribute to the country’s economic growth (Hunter, 2013; Kruss, McGrath, Petersen, & Gastrow, 2015). This connection between higher education and economic growth is emphasised in professional degrees, such as engineering, in which there have been calls to tie the curricula with the industry needs (Jansen, 2002; Matthews, Ryan-Collins, Wells, Sillems, & Wright, 2012). Despite this growing drive to facilitate connection between the economy and the universities, several scholars (e.g., Boni-Aristizábal & Calabuig-Tormo, 2016; Walker, 2015) still see the advancement of disciplinary knowledge and the development of effective citizenship among students as an essential role of the university.

While work has been done to understand to explore the role of universities from the perspective of students, the student-led protests associated with the #FeesMustFall movement during 2015-2017 reveal that student expectations in the South African context are both varied and complex. It is clear that some attempt should be made to ascertain student expectations in the current generation. This is important to understand how students perceive the role of universities so that effective measures can be taken to meet students’ expectations, and, at the same time, efforts can be made to address the misconceptions that students may have about the role of the university. In the context of South African higher
education, the protests under the umbrella of the #FeesMustFall movement drew attention to issues facing higher education in the country including systemic discrimination in higher education institutions, declining government funding leading to rising costs of higher education, and calls for decolonization of the university curriculum. However, the protests related to the movement used violent means and disrupted the functioning of the universities pushing the universities to a vulnerable situation, which may result in something of a pyrrhic victory (Jansen, 2017). It is against this background that we seek to explore the perceptions of first year chemical engineering students with respect to the responsibilities of the university.

Literature review

The context of STEM disciplines

The connection between science, technology, engineering, and mathematics (STEM) disciplines and innovation and economic growth has been widely agreed upon (Boateng, Bensah, & Ahiekpor, 2012; Chowdhury & Alam, 2012; Hunter, 2013). It is an assumption in both developing and developed countries that STEM disciplines will provide graduates who will make a positive contribution to the economy when they enter the workforce (UNESCO, 2009). This assumption is evident in applied disciplines like engineering, which have an emphasis on solving practical problems of society and industry. It is not surprising then that there have been several calls to update the engineering curricula to meet the needs of industry (Bauer, Brooks, & Sandrock, 2014; Matthews et al., 2012), and efforts have been made to design engineering curricula to graduate engineers equipped to support industry needs (Tamin, Du Plooy, Von Solms, & Meyer, 2018; Tamin, Meyer, & Nel, 2016).

However, it has been argued that STEM disciplines should not only be concerned with producing work-ready graduates. Many scholars (e.g., Boni-Aristizábal & Calabuig-Tormo, 2016; Walker, 2015; Walker & McLean, 2013) suggest that STEM graduates need to develop additional capabilities that empower them to make the world a more just and equitable place to live. Walker (2015) rhetorically asks and herself struggles with what a science education might look like if it fosters the values of equity, empowerment, and sustainability. She, along with Mclean (Walker & McLean, 2013), identify eight capabilities that universities should help graduates attain including “informed vision; affiliation (solidarity); resilience; social and collective struggle; emotional reflexivity; integrity; assurance and confidence; knowledge and skills” (Walker, 2015, p. 423).

South African higher education context

During the apartheid era, higher education institutions in South Africa were segregated based on racial and ethnic lines, with an unequal access to higher education for students of different races. This discrepancy in the access to higher education led to differences in the participation rates among different racial groups. As a result, at the end of the apartheid era in 1994, the Black South Africans, who constituted 80% of the country’s population had less than 10% participation rate in higher education. Conversely, White South Africans, who made up only 10% of the country’s population had a 70% participation rate. Indians had a participation rate of 40% and the Coloureds had a participation rate of 13% (Sehoole & Adeyemo, 2016). Even though the BIC population groups in South Africa were granted some access to education, the curricula taught at the universities remained largely Eurocentric with an uncritical assumption that this education was “civilising” the native Black population (Adam, Moodley, & Moodley, 1993).

With the end of the apartheid regime, there has been a push to mitigate some of the inequalities of apartheid by increasing access to higher education of the traditionally disadvantaged groups. The National plan on Higher Education (Ministry of Education, 2001) has identified five major policy goals. These include:
To provide access to higher education to all irrespective of race, class, gender, creed, or ability status in such a way that the graduates are equipped to fulfil the human resource needs of the country

To address the inequities of the past and promote equity by ensuring that the student and staff profiles match the demographics of the country

To address the regional and national needs for socio-economic development through achieving diversity in the higher education landscape

To build research capacity to address the research and development needs of the country

To promote collaboration among regional institutions

These principles clearly highlight the importance of not only developing the research capacity and producing graduates who are ready to tackle the socio-economic challenges of the country, but also addressing the inequities of the past through broadening participation. This need for broadening participation was not only limited to increasing the number of underrepresented groups in higher education, but also to design curricula and teaching and learning processes in such a way so as to accommodate a diverse body of students from different races, genders, socioeconomic backgrounds, and age (Department of Education, 1997).

Over the next decade, the enrolment patterns at the South African universities gradually changed with more Black South Africans getting admitted to the institutions of higher learning. However, the success rates for Black students remained distressingly low (Scott, Yeld, & Hendry, 2007). In addition, it now evident, that Black students continued to experience a sense of cultural alienation at traditionally White universities. This combined with financial exclusion due to the rising fees and perceived institutional racism led to a country-wide movement at the universities known as #FeesMustFall (Jansen, 2017; Langa, 2017).

#FeesMustFall

The #FeesMustFall movement refers to the student-led protests throughout South Africa against the rising cost of tertiary education that started in 2015. While there have been other student protests in the post-apartheid South Africa, especially at historically Black universities, these did not get as widespread media coverage as the #FeesMustFall movement. The movement quickly became one of the most important student protests in the country in the post-apartheid era (Langa, 2017). Whilst #FeesMustFall is most easily associated with the call for reduced tuition fees, it had from the beginning a broad agenda for gender, racial, and social inequalities present in the South African society that are perpetuated through the present university system. This is in no small part because it emerged from successful, albeit violent, campaign to remove the statue of Cecil John Rhodes from a prominent position overlooking the rugby fields at the University of Cape Town. This campaign was known as #RhodesMustFall. Once #FeesMustFall had successfully gained response from the South African Government on the issue of tuition fees, energy was expended on the broader demands of access and decolonisation of education and gender and racial inequities at the universities in terms of staff compensation and recruitment (Jansen, 2017).

Situating this study

As mentioned above, it is clear that there are competing agendas for the vision of higher education. Policy makers, scholars, academics, students and activists all hold different views of what is most important (Jansen, 2017; Langa, 2017). In this paper we seek to add some voices of first year students to the conversation. To this end, this paper addresses the following question: How do first year engineering students describe the university’s responsibilities towards students?
Methods

Participants for the study

Participants for this study included 38 first year chemical engineering students enrolled at two South African universities (U1 and U2). One of these universities is historically English university and the other a historically Afrikaans university. A total of 24 students were interviewed at U1 and 14 were interviewed at U2. These interviews were conducted in the second half of 2017, when the #FeesMustFall protests were in their last phase.

It should be noted here that several scholars (e.g., Becher, 1981; Biglan, 1973; Donald, 2002) have argued that academic disciplines differ from one another in terms of the nature and structure of the knowledge that forms the core of the discipline. These differences give rise to differences in teaching and learning approaches, and assessment practices. For example, as an applied discipline, engineering has a strong emphasis on problem solving with verifiable correct answers (Donald, 2002; Jonassen, 2014). As a result, students’ expectations of teaching and learning at the university may differ based on discipline. This is supported by a recent study by Murzi (2016) in which the author found that engineering students valued technical skills over professional ones, and valued problem solving through the application of already existing knowledge over creativity and innovation. Additionally, given the close ties of engineering with industry, it is quite possible that students may have different perceptions of the university’s responsibilities as compared to students in other disciplines.

Data collection and analysis

Data collection was done as part of a larger longitudinal study that aims to understand how students develop their agency through engagement with the curricular knowledge in two different STEM disciplines (Ashwin, 2019; Pitterson, Case, Agrawal, & Hasbun, 2018). This paper focuses on the segment of the data collected from first year chemical engineering students that explores how they perceive the university’s responsibility. Data were collected in the form of semi-structured interviews in which students were asked questions about their perception of the university’s responsibility towards them and what changes they’d like to see in terms of what services the university is providing them. Interviews were done in English (37 interviews) or Afrikaans (1 interview) to allow students an opportunity to express themselves in the language of their choice. The interview conducted in Afrikaans was translated into English for analysis.

The transcribed interviews were analysed using an inductive coding scheme to extract the major themes occurring in the data. To improve the reliability of findings, Authors 2 reviewed the initial set of themes developed by Author 1 along with the coded data and discussed any disagreements until a consensus was reached. The themes were modified following the discussion. The final set of themes, along with their operational definitions, are presented in Table 1. The table also presents the number of interviews coded for each theme to give an estimate of the frequency of occurrence of each theme.

Results

As presented in Table 1, we identified seven major themes representing students’ expectations of the university. These included academic support, academic environment, extra-curricular activities, individual development, wellness, safety, and managerialism. Frequency denotes the number of students who mentioned this theme in their interview. The following sections discuss these themes in detail along with representative quotes.
Table 1: Final set of themes

<table>
<thead>
<tr>
<th>Theme</th>
<th>Frequency</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Academic support</td>
<td>28</td>
<td>Relates to direct academic support such as good teaching, effective curricula, good infrastructure, and producing work ready graduates</td>
</tr>
<tr>
<td>Academic environment</td>
<td>4</td>
<td>Relates to the university creating an inclusive and conducive academic environment</td>
</tr>
<tr>
<td>Extra-curricular activities</td>
<td>3</td>
<td>Relates to the university supporting students beyond academics, with extra-curricular activities</td>
</tr>
<tr>
<td>Individual development</td>
<td>2</td>
<td>Relates to the university helping students develop as individuals</td>
</tr>
<tr>
<td>Wellness</td>
<td>11</td>
<td>Relates to the university providing facilities such as living spaces, transport, health (including mental health)</td>
</tr>
<tr>
<td>Safety</td>
<td>8</td>
<td>Relates to the university ensuring student safety on campus and in living spaces</td>
</tr>
<tr>
<td>Managerialism</td>
<td>5</td>
<td>Relates to the university functioning like businesses or students themselves thinking of themselves as the university’s customers</td>
</tr>
</tbody>
</table>

Academic support

Academic support was the most frequently occurring theme in the data with about three-quarters of the students expecting the university to provide this. The academic support that the students expected varied from good teaching to incorporating effective curricula to providing adequate infrastructure to producing work ready graduates. For example, a student reflected:

[The university’s] first and most important responsibility towards me is to give me the opportunity to excel academically at what I do, so as long as they provide me with competent, expert lecturers in my subjects and they give the me the material I need to study my course and they give me everything I need to complete my academic course. [U2CHE9]

In this quote, the student noted that the university should provide them with support to help them succeed academically. This support included competent lecturers, adequate study materials, and anything else that might be required to finish the course. Other students emphasized the need for academic support geared towards making them work-ready by the time they graduate from their four-year degrees. For example, a student noted:

They are responsible for preparing me for the workplace. For being able to enter the job market when I leave. I can apply and get in. To be able to go and work in multiple fields and that I am not restricted to anything. To be able to not only work in South Africa but to work elsewhere. [U1CHE9]

As is evident in this quote, the student expects the university to provide them with adequate training and experience so that they are well-equipped to be employed in different fields both in and out of South Africa.

Academic environment

While a majority of students expected the university to provide them with adequate academic support, a few students also emphasised the need for creating an academic environment that is conducive to learning and is diverse. One student also discussed the need for the university to effectively manage the protests so that the teaching and learning process could take place without disruption. The student reflected:
I think the university has been through a bit of turmoil in the last few years with all the protesting that have taken place. And a lot of issues that were always there but that have now risen to the surface. I think the university… it is also their responsibility to look at handling these situations well and look at these situations from everyone’s point of view. But I wouldn’t change, if they say now with the protesting, if there is, certain students are stopping other students from being able to have an education and then they will take action against that. I think everyone have the right to have their voice heard, but I also think everyone has the right to education. [U1CHE16]

In this quote, the student noted that the university should work toward providing a conducive academic environment by ensuring that the teaching and learning activities are not being affected due to the ongoing protests. This quote could have been in response to the frequent shut-down of the university during the protests, which affected the usual class schedules.

### Extra-curricular activities

As students recognized the importance of the academic support and the academic environment and expected the university to provide adequate resources and environment to succeed, some also noted that the university has a responsibility to provide for facilities and resources so that students could engage in extra-curricular activities such as sports and socialize with other students. Additionally, one student noted that not only should the university should provide avenues for extra-curricular engagement but also adequately advertise these opportunities. As the student noted:

> I feel like communication about the societies should be a little bit clear, like I would like it if they put up more posters or they sent out more emails about all the different societies, but I also feel like it is my responsibility to go find out about the societies, like I know there is a list on <university’s learning management system>, which is the university’s website that I can check out, but I would like it if it be more advertised, you know. [U2CHE13]

From this quote, it appears that the student does not distinguish between activities permitted by the university, for example, activities run by societies, and activities run by the university, for example, additional support programs.

### Individual development

Besides academic support and facilities for extra-curricular engagement, two students also emphasised the role of the university in helping them develop individually. This individual development moved beyond leaning the knowledge of the course content and extended to developing social awareness and effective citizenship. As a student reflected:

> I think their responsibility is to grow me in all aspects I mean I go to school here, I live in residence and the university makes up a large part of my life so it their responsibility and what I think is doing exceedingly well is not only developing me as an academic but developing me as a person that is to enter society one day and apply the knowledge that I studied here. [U1CHE4]

In this quote, the student noted that the university is responsible for their all-round development including both academic knowledge and social awareness so that they could apply the learning they had at the university to solve societal issues. However, it should be noted that only two participants noted the individual development as one of the responsibilities of the university.

### Wellness

Wellness, noted by several participants, was another major theme in the data. Students expected the university to provide them with adequate living spaces, meals, transport to and from residences to classes, and physical and mental health facilities. Out of all these aspects
of wellness, mental health was noted the most frequently. Regarding mental health, one student noted:

I think the responsibility of the university towards me is to be able to provide psychologists I think. Like something that...you see how...okay we have so much work to do and sometimes everything just take its toll on you. So, I think the university's responsibility is to provide strong support structures. Because they do say that they have strong support structures but when you go, for example in our department I think we only have one psychologist. [U1CHE24]

In this quote, the student noted how the pressure of studies can take a toll on the student and hence, it is important that the university provides with adequate mental health services that can help students cope with the stress of being at the university. Additionally, the student noted that currently the university did not have adequate mental health support.

Safety

Aligned with wellness, some students also expected the university to provide for their safety. The safety expectations were not only when students were in their residences but also when they were on campus. It should be noted that some these safety concerns were linked with the ongoing protests associated with the #FeesMustFall movement, which at times went violent. As a student reflected:

I think their main responsibility is to give us adequate teaching with and having use of the equipment and then now with the protests it is regarding our safety. [U1CHE23]

As evident in this quote, the student noted that besides providing academic support in terms of adequate training, ensuring student safety is another major responsibility of the university in light of the ongoing protests.

Managerialism

Amidst the various expectations that the students had of the university, we also identified some traces of managerialism in how students saw themselves as customers and expected to receive adequate support and services so that they could get their money worth. For example, one student reflected:

They don't just [have the responsibility] to give me a good education. Yes, so that's like the main responsibility, like give me what I'm paying for. So I expect the food that I pay for at the residence to be not the greatest, like I sort of want enough of what I'm paying for. [U2CHE11]

In this quote, it is quite evident that while the student expects the university to provide them with good education or adequate living conditions, these expectations stem from the student seeing themself as a customer of the university. The student clearly noted that they expect the university to provide them services that are in line with what they are paying to the university as various fees. However, some students also disliked the managerial aspects in the functioning of the university by critiquing the business-like functioning of the university. For example, a student reflected:

I would just like them to not make a university into a money-making scheme if that makes sense. I would like the university to stay a place for getting more education and getting more information and for learning. Not to make everything about money and all of that. [U1CHE11]

In this quote the student expressed how they would like the university to be a place of teaching and learning instead of the university acting like a business that holds profits and finances as paramount treating student learning as secondary. However, it should be noted that this critique of managerialism was only against the university acting like a corporation, and not against the students themselves expecting to be treated like customers.
Discussion

Our preliminary analysis of data suggests that first year chemical engineering students expect the university to provide adequate academic support. This finding is consistent with the idea that teaching and learning forms one of the primary functions of a university (Archer, 2017). However, it should be noted that a significant number of students linked the academic support that they expected to get from the university to their employability when they graduate. This link between academic support and employability is typical of professional degrees, such as engineering, which are expected to produce work-ready graduates who will drive the country's economy (Hunter, 2013; UNESCO, 2009). Students’ expectations of the university to prepare them to be employment-ready can be also explained based on the fact that a lot of students decide to study engineering because of the available employment opportunities in the field after graduation (Painter, Snyder, & Ralston, 2017).

Students’ concern about safety, especially on university campuses, hint at the unrest that was caused during the #FeesMustFall protests that not only disrupted the normal functioning of the university but, at times, also became violent, endangering the lives and safety of students and staff on campuses (Jansen, 2017; Langa, 2017). However, aligned with the safety concerns were the expectations of the university providing for adequate housing, meals, and health facilities. These expectations point to the growing welfarisation of the South African universities (Jansen, 2017). Welfarisation of the universities is the notion that students’ basic material needs must be satisfied by the universities. These needs include but are not limited to free health programs, counseling services, Wi-Fi and computer facilities, and transport services. Jansen (2017) notes that these expectations are not only beyond what was expected of modern universities but also almost impossible to meet given the limited budgets that universities have.

Future work

While this paper gives significant insights into first year chemical engineering students’ expectations of the university, it also opens avenues for further research. Future research can be done to understand how students’ perception of the university’s responsibility change as they gain more university experience and advance through their undergraduate degrees. A select group of these 38 students were interviewed during the second year of their degrees. We are currently in the process of analysing those data.

Future research can also be done to juxtapose students’ perceptions of the university’s responsibility with their perceptions of their own responsibilities. In this paper, we focused only on students’ perception of the university’s responsibility but, guided by Lake’s (2013) facilitator university model, we believed that the university environment is one of shared risks, rights, and responsibilities. Hence, incorporating students’ perception of their own responsibilities in future analysis will give us a more complete picture of how students see themselves in the facilitator university model. Additionally, to gain a deeper insight into the managerial aspects in students’ and universities’ roles and responsibilities, this analysis can be complicated by considering the source of funding for students.

Future research can also be done to highlight institutional, disciplinary, and national similarities and differences in students’ perception of the university responsibilities. Prior studies (e.g., Agrawal et al., 2018; Lee, 2007) have established that students’ experiences at universities result due to a complex interaction of national, disciplinary, and institutional cultures. For the larger longitudinal study of which this paper is a part of, data were collected from first year students for this study at various universities in different countries in two STEM disciplines. A future analysis can be done to compare and contrast students’ experiences based on nationalities, academic disciplines, and institutions.
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Multimodal representations for teaching problem solving in engineering dynamics: The case of a lecturer at a South African university

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Abstract: This paper responds to the concern that students solve engineering dynamics problems procedurally without conceptual understanding, by offering a focus on using representations (or multimodal language) for modelling problem solving in the lecture space. This is a detailed qualitative case study of the pedagogy of a lecturer teaching dynamics in a professional undergraduate programme. A social semiotic multimodality perspective is applied to a lecture recording and lecturer interview to investigate (a) how the lecturer uses multimodal language to give meaning to procedural skills, conceptual knowledge, roles and relations for dynamics problem solving, and (b) how this is shaped by her purposeful, contextual choices. Evidence is provided that she uses language resources offered by technological and other media to communicate a detailed, logical problem-solving heuristic underpinned by key aspects of dynamics concepts, while identifying herself and the students as solving challenging problems. The knowledge produced in a case such as this can inform engagement with engineering lecturers on the centrality of language use for sharing disciplinary meanings, an engagement that is grounded in an understanding of each lecturer’s purposeful and contextual choices.

Introduction
Solving well-structured problems is a central activity in core undergraduate engineering subjects (Litzinger et al., 2013). Commonly, students are taught heuristic strategies for guiding the problem-solving process (e.g. Jonassen, 1997). In engineering dynamics (henceforth, dynamics), students apply concepts such as velocity and acceleration to solve problems about motion and forces in machinery. However, dynamics students may use a heuristic simply as a set of procedural steps without the necessary conceptual understanding required as future engineers (Fang and Guo, 2013). This concern has provoked research on dynamics problem solving, with a particular focus on using technological media such as simulations and interactive tutorials to improve performance (e.g. Cornwell, 2004; Fang and Guo, 2013; Schmidt, 2011).

We approach this research problem with a focus on the use of representations for modelling problem solving in the lecture. The role of representations in the form of written and verbal language, mathematical symbols, and various images such as sketches of mechanisms and vector diagrams in problem solving is recognised (e.g. Johri, Roth and Olds, 2013; McCracken and Newstetter, 2001; Moore et al., 2013). Yet there is a need to further understand the role of language in both student learning and social interaction (Case and Light, 2011), and to use new theories of representation to achieve this (Johri, Roth and Olds, 2013). In addition, given the attention to technology for improving problem solving performance in existing research, and arguments that digitised media have changed how we communicate and access information (Kress and Selander, 2012), there is a need to extend our understanding of representations for problem solving in digital media.
Our focus on the modelling of problem solving in the lecture is motivated by our context and the broader literature review. Firstly, we note that in resource-constrained contexts such as ours, the time-constrained lecture remains a key pedagogic site, and the opportunities to use digital and other media may be constrained by what is available in lecture venues. Secondly, while the crucial role of the lecturer in creating opportunities for students to use representations for learning is recognised (e.g. Tang, 2013; Fredlund, 2015), it is argued that, since using representations is a non-linear process, creating these opportunities in the lecture is challenging (Moore et al., 2013). Indeed, in the active learning trend in engineering education, the lecture has typically been associated with a static pedagogy and student passivity (Villanueva et al., 2018).

This paper draws on a wider study of language use in dynamics in a professional undergraduate engineering programme at a South African university. The focus here is a qualitative case study of the lecture pedagogy of one of the lecturers in the four member dynamics lecturing team. Using a theory of social semiotic multimodality we ask, (a) What procedural skills, conceptual knowledge, roles and relations for problem solving are modelled in the lecture? (b) How are representations used to communicate these meanings? and (c) Why does the lecturer make particular pedagogic choices?

This is in fact the second in-depth qualitative case study of lecture pedagogy for modelling problem solving within the broader study. We, the authors of this paper, are education development practitioners working with this team of dynamics lecturers, all of whom bring different experiences to their dynamics teaching. The research knowledge produced in each case study will form the basis for our engagement with the lecturers. As suggested by Fredlund (2015), a lecturer’s planning needs to be informed by a detailed unpacking of the dynamics knowledge, roles and relations, and how representations are used to share and promote access to these valued ways of problem solving (research questions (a) and (b)). This engagement is grounded in our understanding of an individual lecturer’s choices in this regard (research question (c)), rather than in decontextualized comparisons of pedagogy, as we strive to avoid deficit positionings of lecturers in appreciation of the value of the diverse experiences of our colleagues.

Theoretical framework

Social semiotics views representations as social in the sense that representations are both shaped by and shape social practices, and are thus central to disciplinary meaning making. From Halliday’s (1973) initial focus on written and spoken language for meaning making, social semiotics has been developed to include other representations – or language modes – such as symbols, images, and gestures. Hence the term social semiotic multimodality, as used by Jewitt (2014). This perspective has been used in school science (e.g. Kress et al., 2014; Tang, 2013), university physics (e.g. Airey and Linder, 2009; Fredlund, 2015), engineering design (e.g. Artman, House and Hultén, 2014) and civil engineering (Simpson, 2015), and next we describe how we use the key concepts in relation to dynamics.

In a professional undergraduate engineering programme, dynamics students are required to use physics and mathematics concepts first encountered in other subjects to solve complex problems flexibly and creatively as future engineers. Thus, we draw on but supplement social semiotic concepts used by Airey, Linder and Fredlund in university physics. We argue that dynamics has a coherent system of concepts for thinking about phenomena (Airey and Linder, 2009), procedural skills for using relevant concepts to generate problem solutions (Fang and Guo, 2013), and certain roles for and relations between participants. From a social semiotic multimodality perspective, the valued knowledge, skills, roles and relations in dynamics have been shaped over time by, and are shared within, the disciplinary community (Kress et al., 2014). Crucially, these valued ways are developed, shared and accessed through the multimodal language of the discipline (Airey and Linder, 2009). A mode, such as
symbols or a vector diagram, is specialised to perform particular disciplinary-specific meanings (Kress et al., 2014).

Given our interest in problem solving with conceptual understanding, we note that a concept has what are referred to as key aspects ‘...which are necessary for constituting a broader and richer experience’ of the conceptual system within a particular discipline (Airey and Linder, 2009, p. 31). A student needs to become fluent in a ‘critical constellation’ of language modes for accessing these aspects in order to ‘holistically’ experience a concept (p. 28). In our study we are interested in how, when modelling problem solving using the concept of motion relative to rotating axes, a lecturer uses language modes to unpack the key aspects of this concept, such as sliding and rotating motion, and vector magnitudes and directions.

Finally, from a social semiotic multimodality perspective, how a dynamics lecturer uses language to share and promote access to dynamics is shaped by the discipline and wider context, but is also agentic and purposeful (Kress and Selander, 2012; Tang, 2013). In this paper we draw on an interview with the lecturer to understand her pedagogical choices.

**Methodology**

The course in focus in this paper is a core dynamics course (Dynamics I) in a professional undergraduate engineering programme at an English-medium South African university. Ethics approval for the study was obtained from our university. As noted, at the time of the study the course was lectured by a four member team. In this case study we focus on how one lecturer models problem solving involving the concept motion relative to rotating axes. This is a pinnacle concept in Dynamics I, requiring understanding of simultaneous sliding and rotating motion and of previously established concepts such as velocity, acceleration, and vector magnitude and direction. Thus we are interested in how she uses multimodal language to unpack these key aspects of the concept. The media available to her in the raked lecture venue (with a capacity of 120 students) were multiple sliding chalkboards, a data projector projecting on an audio-visual screen above her height, and a document camera using the same screen.

We draw on two data sources: a written transcript of an audio-recording of a semi-structured interview with the lecturer, conducted by the authors, in which she talked about teaching the course; and a transcript of a video-recording of a lecture on problem solving. The latter transcript was obtained from an auto-tracking camera focused on the front of the venue as well as recordings of the projector slides and document camera. The lecture recording was transcribed to represent the lecturers’ speech, written text, images, movement, position, gestures and gaze. Given the representational nature of our transcripts, we regularly revisited the recordings during analysis.

We performed a thematic analysis of the interview transcript, with themes guided by the research problem in our and other contexts. This included, for example, reports of students’ difficulties solving problems with conceptual understanding, possible pedagogic strategies for addressing this problem and the role of language in the learning of dynamics.

To analyse the lecture transcripts we used Halliday’s (1973) functional approach to language, which has been used in other social semiotic studies of multimodal language use in science and engineering (e.g. Fredlund, 2015; Kress et al., 2014). From this perspective, language modes perform particular functions by building meaning in a discipline. So, language modes function ideationally by giving meaning to the conceptual knowledge and procedural skills in dynamics. Modes also function interpersonally to give meaning to the roles of the lecturer and students, and how they relate to one another and to knowledge. Thirdly, the textual function refers to how language modes are used to produce a coherent account of the ideational and interpersonal meanings, which is the focus of our investigation of the lecture.
Problem solving in Dynamics I

In this section we further describe Dynamics I and present the problem solved in the lecture, drawing on the lecturer interview to position her in this context. This informs our understanding of her choices regarding what conceptual knowledge, procedural skills, and interpersonal relations are modelled in the lecture, and how she uses language to do this.

Dynamics I has a reputation as being difficult. The lecturer identified students’ ‘confidence’ as a concern, quoting students saying they were ‘nervous’ (underlining for her emphasis) and ‘continually waiting for that point when it’s going to come undone’. The lecturer, who herself studied Dynamics I as an undergraduate student, referred to her sense as a student that she did not know ‘how the things tied together’, thus alluding to her struggles with conceptual understanding. She felt this was exacerbated by the fact that, as a student learning in English as an additional language she, like some students she was now lecturing, had difficulty with the disciplinary-specific meaning of terms. She cited ‘absolute’ and ‘relative’ as examples of such terms. Referring to the prescribed textbook, she felt that students who share her language background ‘have to read and reread and think and think and reread to get to what they’re actually explaining’.

The Dynamics I lecturing team has, in response to concerns about students’ problem-solving performance, adopted two strategies. In the first, after an introduction to the theory of a new concept, the lecturer models the use of the concept for solving well-structured problems. The lecturer in focus in this paper described this as ‘a very logical, methodical way to approach’ problem solving, with modelling in the lecture an opportunity for students to ‘watch how the process needs to actually unfold’. The role of the lecturer is to ‘almost [...] explain every step’, since ‘...to me it’s... knowledge that’s there but to them it’s not’. Yet achieving this accurately when problem solving with the complex concept of motion relative to rotating axes in a 45 minute lecture felt ‘scary’ for the lecturer. To prepare for her lecturing, the lecturer attended the lectures of other teaching team members and read up in the prescribed textbook and additional online resources.

The second lecturing strategy adopted by the team involves the use of vector diagrams rather than the algebraic approach traditionally used in textbooks. In her interview the lecturer in focus in this paper described this strategy as ‘really helpful in term of visualising [...] what is what where’ and facilitating interpretation. As a student who was taught the algebraic method, she ‘could do it’, but felt her procedures were not underpinned by the necessary conceptual understanding. Although vector diagrams were ‘beneficial’, she noted that students could identify the known and unknown vector magnitudes and directions but were ‘hesitant’ to construct the diagram. She suggested it is a ‘conceptual leap’ when ‘you’re dealing with two unknown vectors on one side of the equation and you’re having to draw a construction line from the end of one and a construction line from the other’.

As noted, the specific problem in focus for this paper uses the concept of motion relative to rotating axes (Figure 1). The rotating set of axes is the slotted link CB which is fixed at C. Point A slides with the slot as the mechanism moves, driven by the crank OA. The angular velocity of CB (\(\dot{\omega}_{CB}\)) is found by determining the velocity of A (\(\dot{v}_A\)) using the vector equation:

\[
\dot{v}_A = \dot{v}_C + \dot{v}_{P/C} + \dot{v}_{rel}
\]

The subscripts in the vector equation denote the fixed point C and the virtual point P, a conceptual device allowing the separate consideration of the rotating motion (P/C or P relative to C) and the sliding motion (denoted by \(\dot{v}_{rel}\) or A/P). This equation is solved graphically using a vector diagram and the result is taken forward for the acceleration problem. For rotating motion, acceleration has both a normal (pointing towards the centre of means that nearly twice as many terms appear in the vector equation:

\[
(\ddot{a}_A)_n + (\ddot{a}_A)_t = \ddot{a}_C + (\ddot{a}_{P/C})_n + (\ddot{a}_{P/C})_t + \ddot{a}_{cor} + \ddot{a}_{rel}
\]
As with the velocity calculation, the acceleration equation is solved graphically which finally allows the calculation of the acceleration of $A$ relative to the slot $CB$ ($\ddot{a}_{rel}$).

In the interview the lecturer noted students’ difficulty understanding the ‘fictitious point’ $P$, noting her sense, as a student, that this conceptual device ‘didn’t make intuitive sense at all’. Since she found that students lacked confidence, it was sometimes hard for her as a lecturer to encourage students when faced with challenging concepts such as this one: ‘I just typically try and talk through it and say okay, but you've seen this before. This is how this relates to that. This is how this relates to that.’

Talking about her lecture pedagogy, this lecturer said she used PowerPoint slides as a record of the ‘fundamental guiding principles’, but moved to the board for modelling problem solving. Writing on the board slowed down her description of the problem solving to allow students to get 'insight into the process’. Yet she noted the challenges of this medium such as providing the necessary detail within the given time constraints, using a board protractor for constructing the vector diagram, and working accurately with angles. Thus, she invited student input into the process and ended up giving the engaged students roles such as the ‘angle person’. Indeed, the ‘style director’ was the one who prompted her to use the document camera for constructing the vector diagram rather than the bulky board protractor.

She also said that it was ‘important’ that students asked questions, but she did not expect ‘everyone’ to do this. She identified students such as those learning in English as an additional language and who had attended poorly resourced schools as being ‘a bit shy about sticking out’ in asking their own questions but as benefitting when other students asked questions.

**Dynamics I lecture analysis**

The dominant ideational meaning structuring the lecture is the lecturer’s 42-minute, 13-step problem solving heuristic (Table 1); steps 2 to 9 for calculating the velocity, and steps 10 to 13 for acceleration. The lecturer’s concern about providing detail within the time constraints is seen in the lack of time to complete step 14. The problem was presented on a PowerPoint slide (step 1) and all subsequent steps, other than the use of the document projector (steps 7 and 13), were done on the board. Our analysis shows that, as she acted textually using various language modes to model this heuristic and responded to students’ questions, the lecturer gave ideational meaning to the conceptual understandings that she identified as
problematic in the interview. She also built interpersonal meanings related to the roles and interpersonal relations she identified for herself as a former student and as a lecturer, and for the students in her class needing to pass a challenging course.

Table 1: A 13-step problem solving heuristic.

<table>
<thead>
<tr>
<th>Step</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Reading through the problem text.</td>
</tr>
<tr>
<td>2</td>
<td>Writing down in symbolic form what values are given and what values are to be calculated.</td>
</tr>
<tr>
<td>3</td>
<td>Drawing a sketch to represent the mechanism parts and the motion.</td>
</tr>
<tr>
<td>4</td>
<td>Writing down the relative velocity equation ( \vec{v}<em>A = \vec{v}<em>C + \vec{v}</em>{P/C} + \vec{v}</em>{\text{rel}} ), with appropriate subscripts.</td>
</tr>
<tr>
<td>5</td>
<td>Finding the ‘known’ magnitudes and directions of each vector in the velocity equation and identifying the ‘unknown’ magnitudes.</td>
</tr>
<tr>
<td>6</td>
<td>Drawing a rough sketch of the velocity vector diagram.</td>
</tr>
<tr>
<td>7</td>
<td>Constructing a scaled velocity vector diagram, and measuring the magnitudes of ( \vec{v}<em>{P/C} ) and ( \vec{v}</em>{\text{rel}} ).</td>
</tr>
<tr>
<td>8</td>
<td>Calculating the unknown magnitudes on the velocity vector diagram using trigonometry.</td>
</tr>
<tr>
<td>9</td>
<td>Identifying the information from the velocity calculation that is required for the acceleration calculation (the angular velocity of ( CB ) and ( \vec{v}_{\text{rel}} )).</td>
</tr>
<tr>
<td>10</td>
<td>Writing down the relative acceleration equation ( \vec{a}<em>A = \vec{a}<em>C + (\vec{a}</em>{P/C})<em>n + (\vec{a}</em>{P/C})<em>t + \vec{a}</em>{\text{cor}} + \vec{a}</em>{\text{rel}} ) with appropriate subscripts.</td>
</tr>
<tr>
<td>11</td>
<td>Finding the ‘known’ magnitudes and directions of each vector in the acceleration equation and identifying the ‘unknown’ magnitudes.</td>
</tr>
<tr>
<td>12</td>
<td>Drawing a rough sketch of the acceleration vector diagram.</td>
</tr>
<tr>
<td>13</td>
<td>Constructing a scaled acceleration vector diagram.</td>
</tr>
<tr>
<td>14</td>
<td>Measuring the unknown magnitudes on the acceleration vector diagram, and calculating the required acceleration of ( A ).</td>
</tr>
</tbody>
</table>

Given the difficulty within the constraints of this paper of providing the necessary detailed evidence of how we have used social semiotic multimodality to produce this argument about the complex problem in Figure 1, we focus in the rest of this section on the velocity calculation. We also focus in particular on the issues raised by the lecturer in the interview that include understanding ‘how the things [are] tied together’, students’ difficulties with the ‘fictitious point’ \( P \), making the ‘conceptual leap’ for constructing the vector diagram, and using the disciplinary specific meaning of terms.

After a three-minute recap of the angular velocity and acceleration formulae from the previous lecture, the lecturer brought up the problem (Figure 1) on the screen above her on her right. Glancing between the screen and the computer monitor on the lectern, she read the text aloud (step 1). Then, gazing mostly at the students, she used talk and gesture to give ideational meaning to the parts of the mechanism (\( OA \) and \( CB \)) and their motion, and the process to follow. The inclusive ‘you’ and ‘us’ identifies her and the students as problem solvers:

And so, that crank \( OA \) (holding her hands apart for the length of the crank) is driving our slotted link \( CB \) and is going to give us some information about our point \( A \), which will then enable us to calculate what’s happening along our link \( CB \).

Next, looking at the slide at times, she used symbolic notation to list on the board the information that was given in the problem and what was required (step 2). She introduced step 3: ‘next I draw my diagram’, which is a sketch using lines, symbols and labels to represent the necessary information about the mechanism and its motion (Figure 2A).
Figure 2: Sketch of problem diagram (2A) and velocity vector diagram (2B), both on board.

After labelling her diagram, and talking through the steps as she drew, she signalled the ‘importance as always’ of attending to the two forms of motion in their (‘we’) problem solving. During step 3 her gaze was mainly on the board as she focused on the process of drawing. In Table 2 her careful verbal description gives ideational meaning to the steps for constructing the sketch. Her verbal descriptions, drawing and gestures (both for parts of the mechanism and their movement) also act textually to give ideational meaning to the different circular paths of $A$ around $O$ (2a,b,f) and $P$ around $C$ (2e). These aspects are crucial in understanding the work of the conceptual point $P$ (2d) that enables the separate consideration of the rotational motion of link $CB$ (the rotating axes) and the sliding motion of $A$ in the slot. At times she paused and shifted her gaze to the problem slide, identifying herself as thinking through the process. Her gaze towards the students (2f) invited questions and identifies herself as a lecturer who looks out for students’ responses.

Table 2: Extract from step 3, drawing a sketch on the board.

<table>
<thead>
<tr>
<th>What was said</th>
<th>What was done (refer to Figure 2A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2a We have this circular path about $OA$</td>
<td>drawing a circular dotted line about $A$</td>
</tr>
<tr>
<td>2b where $A$ is located</td>
<td>drawing a large dot at $A$</td>
</tr>
<tr>
<td>2c and we’re interested in what’s happening along my slotted link $CB$.</td>
<td>running hand up the line $CB$</td>
</tr>
<tr>
<td>2d So, I’m going to define my point $P$ coincident with $A$</td>
<td>drawing over the large dot at $A$, adding ‘$P$’ next to ‘$A$’</td>
</tr>
<tr>
<td>2e however, its circular path is going to be about $CB$</td>
<td>running hand up the line $CB$ again, drawing a circular dotted line for the movement of $P$, running hand over it</td>
</tr>
<tr>
<td>2f which is slightly different to the circular path of $A$ which is about $OA$. Okay.</td>
<td>pointing at $A$ and then $O$, looking towards the students</td>
</tr>
</tbody>
</table>

In step 4 the lecturer wrote on the board the relative velocity equation $\mathbf{v}_A = \mathbf{v}_C + \mathbf{v}_{P/C} + \mathbf{v}_{rel}$, with appropriate subscripts. Step 5 involved finding the known magnitudes and directions of the vectors and identifying the ‘unknown’ magnitudes, focusing first on the absolute velocity term $\mathbf{v}_A$. During this step she fielded a student question about the motion of point $A$ and how this was related to the link $CB$ (‘Okay. Yes?’). Her response, in the form of talk and hand gestures for pointing at the slide diagram and board sketch and for motions, gives ideational meaning to the notion of the absolute velocity of a point as opposed to relative velocity. For example, she ran her finger along $OA$ on the board sketch and pointed upwards to the slide diagram to draw attention to ‘this crank $OA$’, and in particular that $OA$ ‘gives motion to my point $A$ (pointing at $A$ on the board sketch, turning right hand over to show rotating motion)’. Thus, since ‘$A$ is also along the crank $CB$ (running hand along slot on board sketch)’, the
circular path of \( A \) around \( O \) 'is driving my slotted link', causing it to rotate. She also named the symbol \( \vec{v}_{A} \) verbally as the 'absolute velocity at point \( A \)'. While giving attention to the two diagrams, the lecturer also cast her gaze on the student; identifying herself as listening to the student and following up on his response to her explanation.

On completion of step 5 the lecturer summarised: 'I end up with an equation where on one side of the equation I have all my information. On the other side I have only one vector that's fully characterised and two \([v_{P/C} \text{ and } v_{rel}]\) for which I know the directions but not the magnitude'. Finding these values would require a vector diagram using the document projector (step 7), but first 'a quick sketch on the board' (step 6, Figure 2B). She focused on the side of the equation that is 'fully characterised', drawing the scaled vector \( v_{A} \). Thus she knows 'where the start point and the endpoint of [...] my triangle in this case' (pointing to each point), and can then 'go to the other side of the equation'.

Table 3 shows how she modelled constructing a vector diagram with two unknown vector magnitudes on the right hand side by giving ideational meaning to the concept of vector addition. Using the board sketch, talk and gestures she identified the 'start point'/'head' and 'end point'/'tail' of vector \( v_{A} \). Then by sketching the relevant angles relative to the horizontal, and using dotted 'construction lines' for \( v_{P/C} \) (3a) and then \( v_{rel} \) (3d), she identified the solution of the vector equation as the intersection of the two lines (3e). Her intermittent gaze at the students invited responses.

| Table 3: Extract from step 6, drawing a sketch of the velocity vector diagram on the board. |
| What was said | What was done (refer to Figure 2B) |
| 3a | We said that \( v_{y} \) was at 30 degrees, so my \( v_{P/C} \) is going to be at 60 degrees, lying somewhere along that line. | drawing a dotted horizontal line and adding angles, drawing dotted line \( v_{P/C} \) through head of \( v_{A} \), labelling \( v_{P/C} \) |
| 3b | ... | ... |
| 3c | So, I know that this is the end point... so what I can then do is attach the direction of my \( v_{rel} \) to this end point. | pointing to and holding her hand at endpoint of \( v_{A} \), looking at students |
| 3d | We said that my \( v_{rel} \) was at 30 degrees to the horizontal, so that will be the construction line for my… \( v \) relative. Okay. | looking up at sketch, drawing dotted horizontal line and then dotted line at 30 degrees for \( v_{rel} \), intersecting \( v_{P/C} \) and tail of \( v_{A} \), looking at students, then labelling \( v_{rel} \) |
| 3e | And where those two intersect … will give me the magnitude of my \( v_{P/C} \). | drawing a dot where \( v_{P/C} \) and \( v_{rel} \) lines intersect, drawing \( v_{P/C} \) as a solid line |

Thereafter the lecturer constructed the scaled vector diagram using the document projector (step 7), and proceeded though the steps described in Table 1.

**Discussion and conclusions**

We began this paper by identifying the need to research pedagogy for dynamics problem solving with conceptual understanding from the perspective of multimodal language use in the lecture. We have applied a social semiotic multimodality perspective, a relatively new theory of representations in engineering education, in the analysis of the lecturer interview and lecture transcripts. This perspective brings into view the lecturer’s multimodal language use (the textual function) for (a) sharing the valued procedural skills and conceptual knowledge (ideational function), and (b) for building roles and relations (interpersonal function). It also allows us to view this pedagogy as purposeful and shaped by her experience of the context both as a lecturer and as an undergraduate student learning in English as an additional language.

We have provided evidence that she used the board and document camera to model ‘live’ how the detail of logical steps in a heuristic for solving the problem unfold. For this she used
written symbols and numerical calculations, two sketches on the board (in addition to the problem and the vector diagrams), and her verbal description of the process. Yet she also integrated into her talk about the procedural steps and responses to student questions explanations of the aspects that underpin the concept of motion relative to rotating axes. These aspects include the simultaneous rotational and sliding motion, the conceptual point \( P \), and vector addition, key aspects necessary for a ‘broader and richer experience’ (Airey and Linder, 2009, p. 31) of the pinnacle concept. To achieve this using language, she supplemented her existing writing, talk and diagrams with gestures for pointing at her diagrams and for modelling motion, and gave specific attention to the naming of concepts such as ‘absolute’ velocity. She also drew on other resources in the context such as using students’ verbal contributions in class to avoid making errors and observing the lectures of other lecturers. We suggest that, with her intense focus on modelling the detailed heuristic with conceptual underpinnings, but also attending to student responses at regular intervals, she balanced communicating to students the challenging nature of the task and encouraging them to build on their existing understandings.

We have also shown that she identified the students as problem solvers needing to follow logical procedural steps and as needing to have the key conceptual aspects underpinning the heuristic explained, including the specific meaning of dynamics terms. These students were also identified as have a contribution to make in the lecture but also as listeners if they preferred. The former was achieved by allocating certain students roles (based on their dispositions) and her regular glances towards these students for feedback. At the same time she identified herself as a lecturer having to focus intently on solving a complex problem, who might make errors and thus makes use of student input, and is responsive to student questions. We note in particular that the ideational and interpersonal meanings summarised here were achieved textually using multimodal language within the time constraints of a 45-minute lecture and using the available technological and other media available in the lecture venue, a space that is generally associated with student passivity (Villanueva et al., 2018) and challenges using representations to build meaning (Moore et al., 2013).

The research presented here is limited to the case of one lecturer modelling the solving of one complex problem. Certainly, the understanding presented in this paper is valuable for our work as education development practitioners engaging with the lecturing team in a context where the lecture is the dominant pedagogical space. Our use of a social semiotic multimodality perspective is productive for this engagement in three respects. Firstly, a detailed analysis such as this forms the basis for the team’s developing understanding of the valued procedural skills, conceptual understanding, roles and relations for dynamics problem solving. Secondly, the centrality of language for disciplinary meaning in this perspective allows us to explore what language modes might provide access to an holistic experience of the problem solving Finally, since social semiotic multimodality regards language use as purposeful and contextual, we can approach this engagement with an understanding of a lecturer’s choices. We suggest that, since the lecture is likely the dominant pedagogical space in other resource-constrained contexts, researchers in such contexts might consider how the theoretical perspective illustrated here might be used to inform education development engagements with lecturers.

We end by noting what can be drawn from this particular case study for further research. We have focused on one complex, pinnacle concept in dynamics and there is a need for us to develop a deeper understanding of the key underpinning aspects of the conceptual system for engineering dynamics, and also how the concepts are harnessed for solving problems in engineering mechanics. Thematic analysis such as that used by Fredlund (2015) is a potential method for this task. Secondly, there is a need to better understand lecturers’ use of language for providing access to the valued ways of problem solving with these concepts for students learning in an additional language.
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The impact of the combined status of race and gender on the persistence of Black female STEM students

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Abstract: This study examines how multiple indicators of identity work collaboratively to determine the impact of the combined status of race and gender on persistence in STEM for Black female students matriculating at an HBCU. Data revealed that students had high private racial regard and gender identity, they perceived low public racial regard, and had high desire and commitment levels to persist in completing their STEM degree.

Introduction

Since 2000, the demand for science, technology, engineering, and mathematics (STEM) professionals has been on the rise in the United States. With an increasing global market, the U.S. struggles to maintain a competitive workforce. Thus, causing a STEM pipeline crisis where the workforce and international competitiveness must expand rapidly. In order for the United States to tackle this dual challenge of an undersupplied STEM workforce coupled with the growing international competition, there must be a focus on global leadership in STEM. Specifically, an emphasis should be placed on fast-tracking the production of women universally and women of color particularly in the STEM workforce.

For decades, researchers in the United States have examined the issues related to broadening the participation, retention, and success of individuals underrepresented in STEM fields. However, there is limited data on one group of underrepresented individuals—Black women, who over time have become an increasingly larger portion of the available talent pool. According to a recent census report, women make up 24% of the STEM workforce (Harper, 2018). Past research on women and Blacks in STEM has not largely focused on the dual identities of gender and race. This dual identity uniquely impacts this population as both their
their gender and ethnicity are classified as a minority status in the United States. Hence, this dual minority status influences the pathways that Black females take to reach degree goals and be successful in STEM careers.

Historically Black Colleges and Universities (HBCUs) has served as an academic resource to meet the challenges of economic growth and advancement for African Americans. HBCUs have been at the forefront producing African American college graduates for more than a century. According to the National Science Foundation (NSF), 21 of the top 50 institutions for educating African Americans who pursue doctorate degrees in science and engineering are HBCUs (Harper, 2018). Institutions such as Howard University, North Carolina A&T State University, Xavier University, and Florida A&M University are some of the top producers of African American students who attain a STEM undergraduate degree. This occurs primarily because the campus culture of HBCUs offer Black students a sense of community, while boosting self-confidence and efficacy that is necessary for success in the labor force (Perna, 2009).

With this in mind, looking through an intersectional lens establishes a framework for understanding how multiple indicators of identity work collaboratively to determine social experiences, knowledge production, and systems of subordination (Cho et al, 2013) for Black female STEM students matriculating at an HBCU. This study explores the impact of the combined status of race and gender on persistence in STEM of students at an HBCU where their race is considered to be in the institutional majority. The intersection of these identities may lead to different experiences than the mutual exclusivity of race or gender on persistence. In addition, we aim to contribute to the literature by expanding the knowledge base of this understudied population (i.e. Black female students at a historically Black university) which will allow the STEM community to identify where additional research work is needed and provide a more comprehensive look at diverse students who are studying in diverse contexts.

**Theoretical Framework**

The theory of intersectionality is applied in this study. Intersectionality is defined as the interconnected nature of social categorizations such as race, class, and gender regarded as creating overlapping and interdependent systems of discrimination or disadvantage. Kimberlé Crenshaw (1989) coined the term intersectionality due to Black women facing hardships connecting or identifying themselves with the issues of the mainstream (white) feminist movement in the US. Particularly on the matter of pressures to be a homemaker. This was primarily because Black women had to work to provide for their families rather than be homemakers. Therefore, Black women could not relate to such an issue because it did not align with their experiences.

The intersectionality theory outlines that people are hindered by various sources of oppression such as their race, gender, class, sexual orientation, religion, and other identity indicators. Intersectionality acknowledges that identity indicators such as gender (e.g. female) and race (e.g. Black) are interconnected rather than independent of one another. Intersectionality outlines the framework of theorizing a person, group of people, or social problem that is impacted by a number of perceived shortcomings. In doing so, such identities intersect to aid in the understanding of prejudices people face. The lens of intersectionality critically recognizes the inequality and intricacies of lived experiences of Black women.
Methodology and Sample Size

This study aims to understand how racial identity, gender identity and their intersection influence Black female STEM undergraduates' desire to persist in their degree programs and pursue graduate education. This longitudinal study utilizes a convergent parallel mixed methods study approach to answer the following questions:

a) How does the racial identity, gender identity and their intersection influence the academic identity of Black female STEM majors? b). How does racial, gender and academic identity (and their intersection) influence the persistence and academic achievement of Black female STEM students in their disciplines?

In light of the parallel collection of both interviews and surveys, researchers used convergent parallel mixed methods as the primary methodology (Creswell, 2012, 2018), because it provides segments of both qualitative and quantitative research on the same measures. Delaney, McCarthy, and Beachum (2017) adds that mixed methods “supports a more pragmatic approach to research” since its combination of qualitative and quantitative methods provides a more comprehensive view of the research problem than a single method.

This longitudinal study utilizes the first two years of data gathered from annual surveys and individual semi-structured interviews. For the purpose of this paper the quantitative data included came from the centrality, public and private regard scales of the Multidimensional Inventory of Black Identity (MIBI:Sellers, 1998), and the Modern Sexism Scale (Swim et al., 1995) and the Gender Role Preference Scales (Becker & Wagner, 2009). Academic achievement was measured using self-reported overall grade point average and major grade point average (only collected in year two). Collectively, a 92-item survey was administered to Black female STEM majors at an HBCU during their sophomore and junior years of matriculation. Students were given autonomy in completing their surveys and all information received was self-reported.

Qualitative data consisted of one on one interviews, whereas the questions corresponded with the primary research questions and the questions probed in the survey. Interview transcripts and notes were stored and analyzed in NVIVO 12 qualitative software. Data were coded by a team of researchers utilizing an inductive method and allowing emergent themes to surface.

The sample size included 40 Black female STEM students matriculating at an historically black university (HBCU) in the eastern region of the United States. These 40 students participated in an annual survey that was electronically administered. Eighteen students of this sample were also interviewed during the 2016-2017 (sophomore) and 2017-2018 (junior) academic years respectively. At the time of the research window, all participants self-identified as female and classified as sophomores in 2016-2017 and juniors in 2017-2018. Additionally, each participant self-identified as a person of African descent.

Findings and Analysis

The analysis of the qualitative and quantitative data supports the findings articulated below.
Quantitative Results

Quantitative analyses were employed to understand the relationships between Black identity, as measured by the MIBI (Sellers et al., 1998), sexist attitudes and beliefs as measured by the Modern Sexism Scale (Swim et al., 1995), gender role preferences (traditional or progressive) as measures by the Gender Role Preference Scale (Becker & Wagner, 2009) and academic achievement, as determined by grade point average. The MIBI has three subscales: centrality, which determines how central Black identity is to overall identity; private regard, which determines how an individual privately feels about Black people, and public regard, how an individual perceives other (non-Black) people feel about Black people.

A Pearson’s r two-tailed correlational analysis addressing Year One data demonstrated no statistically significant relationships between overall grade point average and centrality, private regard, public regard, modern sexism, or gender role preference. Further analyses demonstrated statistically significant positive correlations between centrality and private regard, $r = .533$, $n = 40$, $p > .01$. The more central Black identity was to participants’ core identity, the more positively they felt about Black people in general. These variables shared 28% of their variance. This finding was expected, as social identity theory (Tajfel & Turner, 1986) suggests that the more related a variable is to the self, the more positively that variable will be regarded, therefore, it is intuitive that the more central one’s Black identity, the more positively one feels about Black people. This finding was even more intuitive when considering the participants were Black women attending an HBCU and was further supported by the qualitative findings.

There was a negative correlation between centrality and gender role preference, $r = -.402$, $n = 40$, $p > .01$. Low scores on the centrality subscale of the MIBI represented high centrality, while high scores on the Gender Role Preference scale represented more gender progressive attitudes. The more central Black identity was to participants’ core identity, the more progressive participants were. These variables shared 16% of their variance. This suggests that Black women for whom Black identity was very important were also more likely to have egalitarian beliefs. This finding is supported by history of the Black female experience in the United States. When White women began the Women’s Liberation movement, or the Second Wave of Feminism, Black women were much more likely to have jobs outside of the home (hooks, 1982). It is no surprise that Black female STEM undergraduates attending an HBCU reported high Black identity centrality and gender progressive attitudes.

A Pearson’s r two-tailed correlational analysis addressing Year Two, participants’ junior year in college, data demonstrated a statistically significant positive correlation between overall GPA and major GPA, $r = .759$, $n = 38$, $p > .759$. An increase in overall GPA meant an increase in major GPA, as expected. These variables shared 58% of their variance. There was a negative correlation between overall GPA and modern sexism, $r = -.354$, $n = 38$, $p > .01$. As GPA increased, scores on modern sexism were lower, which indicated less sexist attitudes. These variables shared 13% of their variance. This finding suggests that as women excelled, they demonstrated less modern sexism toward women than women who performed poorly academically. Modern sexist attitudes suggest that women are equal to men across domains, such as professional and personal. Women who academically excel may have more exposure to professional or academic inequality with their male counterparts in male dominated fields, than women who do not excel and are therefore more likely to fit negative stereotypes about women in STEM.
There was a negative correlation between GPA and centrality, $r = -.488$, $p > .01$. The higher the GPA, the less central Black identity was to core identity. These variables shared 24% of their variance. There was a negative correlation between overall GPA and private regard, $r = -.444$, $n = 38$, $p > .01$. The higher the GPA, the less positive were attitudes about Black people in general. These variables shared 20% of their variance. There was a negative correlation between major GPA and centrality, $r = -.461$, $n = 38$, $p > .01$. The higher the major GPA, the less central Black identity was to core identity. These variables shared 21% of their variance. There was a negative correlation between major GPA and private regard, $r = -0.497$, $n = 38$, $p > .01$. The higher the major GPA, the less positive were attitudes about Black people in general. These variables shared 25% of their variance. Though further research must be done to gain a better understanding of these findings, these findings may suggest that even though these women were attending an HBCU, they were becoming more exposed to the professional world of STEM disciplines, which includes few Black professionals. At this time students were more likely to have had summer internships and other jobs in the field, and may have felt that they must distance themselves from their Black identities to academically and professionally succeed.

There was a negative correlation between gender role preference and centrality, $r = -.314$, $n = 38$, $p > .05$. The more central Black identity was to participants' core identity, the more progressive participants were. These variables shared 9% of their variance. Finally, there was a positive correlation between centrality and private regard, $r = .520$, $n = 38$, $p > .01$. The more central Black identity was to core identity, the more positive attitudes were about Black people in general. These variables shared 27% of their variance. These findings were similar to what was found in Year One.

A paired samples t-test was completed to determine whether there were any statistically significant changes in overall grade point average, modern sexism, and gender role preference, and Black identity (centrality, private regard, public regard) from Year One to Year Two. There was a statistically significant difference in scores for gender role preference in Year One ($M = 19.78$, $SD = 5.191$) and Year Two ($M = 22.50$, $SD = 4.188$), $t(39) = -4.164$, $p = .000$. There was a move from a more traditional gender role preference to a more progressive gender role preference between years one and two. This finding further supports the previous quantitative findings. As women progressed in male dominated fields with primarily male professors and peers, they were more likely to experience sexism and inequality for themselves and be less likely to espouse modern sexist beliefs.

There was a statistically significant difference in scores for public regard in Year One ($M = 21.88$, $SD = 2.794$) and Year Two ($M = 16.58$, $SD = 2.602$), $t(39) = 9.888$, $p = .000$. Participants felt that other people had lower opinions of Blacks in year two than in year one. This is intuitive in the current political climate in which the United States is visibly divided on issues that address racism, such as police shootings of African Americans.

There were no statistically significant findings regarding grade point average or Black identity centrality or private regard.

Multiple regression analyses were done to model the relationship between Black identity (centrality, private regard, public regard), gender identity: the (lack of) endorsement of modern sexism and gender role preference) and academic achievement (GPA). Black identity and gender identity did not predict academic achievement in Year One. A multiple regression analysis was used to test if the Black identity and gender identity significantly predicted overall academic achievement in Year Two. The results of the regression indicated that the model explained 41.6% of the variance ($R^2 = .416$, $F(5, 39) = 4.852$, $p = .002$) in GPA. It was found that
modern sexism significantly predicted GPA ($\beta = -.321$, $p = .030$), as did private regard ($\beta = -.327$, $p = .050$).

A multiple regression analysis was used to test if the Black identity and gender identity significantly predicted major academic achievement in Year Two. The results of the regression indicated that the model explained 41.8% of the variance ($R^2=.418$, $F(5,37) =4.588$, $p = .003$) in GPA. It was found that modern sexism significantly predicted GPA ($\beta = -.303$, $p = .046$), as did private regard ($\beta = -.430$, $p = .014$). The multiple regression models suggest that the lower Black female STEM undergraduates are in modern sexist beliefs and the higher they are in Black identity private regard, the more likely they are to academically achieve. In Year One (sophomore year) modern sexism beliefs were a stronger predictor than Black identity private regard, but in Year Two (junior year), Black identity private regard was slightly more predictive than modern sexism beliefs.

**Qualitative Results**

The principal themes that emerged from the qualitative interviews were:

- High private racial regard - “I’m just doing me”
- Low public racial regard – “You have to be really good…to make them want you”
- High levels of commitment – And still I rise

**High Private Regard**

Black female STEM students at an HBCU had a high private regard and were proud of being classified as black and female within a predominantly white and male field. One participant, from the data collected in Year Two said “if you’ve been successful in your STEM major and you’re just continuing and you don’t fall short. That just shows you’re a strong independent Black woman.”

Another said

“[Black women] are bold and very proud of their heritage. They [black women] are very hardworking.”

This theme continued through their third year of school. In an example of high private regard, a student mentioned

“black women have the ability to always rise to the occasion and I have no doubt in my mind that I will rise to the occasion.”

After being asked about being a black woman in STEM another stated this about her racial identity,

“But I love my skin…I love my skin color, I wouldn’t change it. It just is a part of me. So I’m just doing me regardless of what people say.”

**Low Public Regard**

All of the participants had similar views on how other genders, racial groups, or STEM students or men viewed them as Black women in STEM. The participants found that being a black woman in STEM was difficult, as one woman cited,
“being Black and a female honestly is like at the bottom of the totem pole of society. Like, yeah, that’s what it is. That encompasses everything.”

Many participants agreed that this difficulty was seen in others perceptions of Black women. On being a Black woman, a participant said, “you have to be really good. There has to be something in you that’s going to make them want you.” Another specifically spoke to being black within the STEM field,

“Being black, there this also a stereotype about being a black person that we are lazy or incapable as compared to our white -- well, other counterparts. So being a black person in the STEM field, we actually have to go above and beyond again because we’re black and they’re already going to think, oh, they don’t even want it that bad.”

This sentiment was repeated again and again, with someone else specifying that,

“I don’t think people expect black women to be in STEM. It’s sort of an anomaly or something like that, but I don’t understand why. We’re just as capable as men, as white men and women.” “But still, compared to white men, I don’t think I have an equal opportunity.”

Commitment to Persist

Despite admitting their views on how the public perceives them as black women, all of the interview participants expressed high confidence about their ability to attain their degrees. Overall, the participants articulated a high level of determination to persist in their undergraduate degree programs and strive to prove that they can. Students were asked to rate their commitment level to earning their STEM degree on a scale of 1-10. They were then asked to describe why they rated themselves that way. One student stated,

“I’m very committed. That’s just because, like I said, I think I have a point to prove especially since I’m going into a profession that has a low amount or number of black women. Like orthopedic surgeon. I think there’s only like 3 percent of black women that [are] orthopedic surgeons. So I’m very committed.”

Again, another participant added,

“ I’m going to say a 10 not because I’m proud or overconfident, but because I know for sure that I know where I’m going. I have a God who’s never going to let me down. I’m sorry I’m talking about that a lot, but He’s just all that I have. He’s everything to me. I’m sure that I’m going to be successful because even though I’m not perfect, He is and He’s going to help me out. I’m going to put my best foot forward to make sure that I do all that I need to do to be where I’m supposed to be.

A third student scoring her commitment level at a 10 strongly adhered to the idea of completing her STEM degree. During her interview she said,

“I believe that I possess all these skills to be successful as a STEM major. I think that any obstacles that I might face, I will find a way to work around it and still be successful regardless.”

Although most of the students were highly confident in their commitment to completing their STEM degree, a few did not score themselves highly on the Likert scale. One student in particular said the following,
“I wouldn't do like 5 and below because that would show that you really were not confident in who you are as a person, and I can't say that about myself. But I'm not fully like 10 or above a 7 because there are some times that I do feel I'm skeptical about things. Sometimes things get overwhelming, so it's like can I do this, can I not? But I'm more confident than I am less confident.

**Implications and conclusions**

Concern over the declination of women in STEM brought a number of research agendas to the forefront, concerning student persistence in STEM education and more specifically minority student persistence (Palmer et al. 2011; Adelman 2006; Graham et al. 2013; Giannakos et al. 2016; Pedone 2016). One example, Increasing Persistence of College Students in STEM by Graham et al. (2013), discussed the need for more STEM completers, catalyzed by the President's Council of Advisors on Science and Technology (PCAST) in 2012. Graham et al. found that persistence in STEM was rooted in high confidence in one's ability and seeing themselves as scientists. This high confidence was evidenced from our consecutive interviews with the young women and their own and self-identified accounts based on survey information.

This work in progress included the analysis of the interviews and surveys conducted over two years at one HBCU. Data from two additional HBCUs are forthcoming. The corroboration of the quantitative and qualitative findings are beginning to reveal three overarching themes: students had high private racial regard and gender identity, they saw low public racial regard, and finally had high desire and commitment levels when asked about completing their STEM degree. The data also point to differences in years one and two, which likely speak to the maturation of students and their co-curricular experiences related to their exposure in their sophomore and junior years. Data collected in the final academic year in the program shall reveal the level of persistence towards a STEM degree and the extent to which the public and private regard acted as motivators or distractors.

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**References**


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EngStarter: An Open-Hardware and IoT Integrated Education Kit for Enabling Community-Developed Solutions

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Abstract: This paper describes the factors and body of knowledge used to develop an engineering application kit designed for both conceptual learning and application in displaced and marginalized communities, the EngStarter. The specific contribution of this study is the description of an effective engineering education response in emergencies, demonstrating the potential of enabling community development and effective usage of technologies in the delivery of course content. This kit emerged as a result of two years designing and conducting an undergraduate introductory engineering course in the Azraq and Kakuma refugee camps where the research team listened to students’ needs and evaluated contextual opportunities and constraints. In this paper, we describe a work-in-progress study of the development and application of an education kit that complements the coursework and enables students' engineering prototypes to be built and implemented in the community.

Introduction

Education in displacement and emergency settings has a multifaceted role; students do pursue course offerings for securing a job, but education also becomes a source of hope and contributes to a life with dignity (Akesson, 2015; Alzaroo & Hunt, 2003). In this context, engineering education plays a relevant role, because engineers have the skills to build sustainable communities (Lucena, Schneider, & Leydens, 2010). Indeed, a recent report from UNESCO (Wall, 2010) recognizes that “engineering and technology are vital in addressing basic humans needs, poverty reduction and sustainable development” (p. 30).

It was the combination of providing contextually aligned educational tools for emergencies and fostering community development that led the creation of the EngStarter kit. This kit emerged as an educational kit used to enable engineering students’ projects to be fully realized, as university students work to develop projects that respond to their community’s needs. The EngStarter aids in teaching students how to use different sensors, actuators, and internet of things (IoT), while developing practical solutions specific to water management, food security, and energy management. Although the technologies and sensors used in this kit are not new, the EngStarter combines and adapts open tools along with instructional materials targeted to fragile contexts in order to meaningfully support refugees learning about engineering and community development.

In this paper, we begin with an overview of background research to ground the scholarly motivation for this study. Next, we discuss the local context of the two different camps where this tool will be implemented. Moreover, we provide an overview of the undergraduate engineering course that motivated the creation of the EngStarter. The paper then discusses the theoretical literature review that guides our research analysis. We then present our
methodology, discussing the background context, hardware and software development, and curriculum implications driven by community development. The preliminary results are intended to highlight our impressions and results to date. Finally, we discuss ideas for future work and implications of this study for scholarship.

**Background Research**

Education has been discussed as one of the most important institutions to promote stability in fragile settings (Winthrop & Matsui, 2013) and empower people (Mayuran, 2017; McWilliams, 2014; Pherali & Turner, 2018). However, education for displaced communities is a challenge, and this problem is even more complex and intractable in the context of higher education. According to UNHCR, only 1 percent of eligible refugees have access to higher education programs (UNHCR, 2018b). This is a problem that requires not only expanding higher education opportunities, but also ensuring the quality of these education programs.

Education in emergencies is driven both by social development and the individual hope to build a better life (Alzaroo & Hunt, 2003). Engineering courses in fragile settings should reflect this expectation by equipping students with knowledge and skills to solve problems systematically (Eguchi, 2017) through contextually aligned pedagogy. By providing students with necessary and relevant knowledge and developing their skillset, they can become socially empowered and thoughtful about their roles, in particular with their potential role as engineers (Swope, 1943; “Technology, Engineering, and Society,” 2009) and their capacity to make real change within their community (Lucena et al., 2010).

Recent studies in engineering education have described technology tools that support active learning in the classroom (de Graaf, 2005; Dori & Belcher, 2005), including the positive effect of hands-on experience in electronics (Lehtovuori, Honkala, Kettunen, & Leppävirta, 2013) and programming classrooms (Wu, Hsu, Lee, Wang, & Sun, 2014). In light of this educational effectiveness, much attention has been paid to engineering laboratories (Brown, Flick, & Fiez, 2009; Fuhrmann, Mandl, & Shamonin, 2015), virtual labs (Chen, Zhang, & Zhu, 2012; He, Shen, & Zhu, 2014), and simulation software (Abuelma’atti & Qamber, 2002; Mohammadi, Firouz, Aleyf, & Nafar, 2014), where technology tools have become an integral part of engineering education practice. Thus, in recent years, many higher education institutions have started to incorporate electronics kits in university courses (Judge, 2017; Khan & Abid, 2017; Nedic, Nafalski, & Machotka, 2010; Sabag, 2017).

Despite the overwhelming attention paid to technology tools in engineering education, there is an increasing concern to improve and to ensure the delivery of education in humanitarian settings (Tauson & Stannard, 2018; Von Baeyer, 2017). Therefore, recent findings have presented evidence of the ethical considerations (Tauson & Stannard, 2018), pedagogical responsiveness (Daniel & Zybina, 2018), and impact on community development (Freitas, Beyer, Yagoub, & DeBoer, 2018; Makhoul, Alameddine, & Afifi, 2012) as important guidelines to drive pedagogy and curriculum in refugee settings. Thus, this study adds to the literature of education in emergencies by specifically studying technologies as fundamental components that facilitate learning experiences in classrooms in emergency settings.

**Multiple Cases – Jordanian Camp and Kenyan Camp**

Although our study context includes two official refugee camp settings, the camps are very different in terms of population, size, social context, and politics. For example, Azraq hosts the second largest refugee community in Jordan, representing a total of 40,846 people of concern from Syria (UNHCR, 2018a), and it is subdivided into villages with a decentralized administration of services to support quick expansion (UNHCR, 2018a). In addition, Azraq was planned as an emergency response to the influx of Syrian refugees in Jordan in 2014. On the other hand, the Kakuma camp is one of the world’s largest and oldest refugee camps, with a population of 190,000 people from at least 10 different countries. Kakuma was established in 1992 to host Sudanese refugees. It has since expanded due to ongoing and
increased conflicts in the region, with the camp now hosting refugees from other countries as well. Both camps have different structures, but similar problem domains (described in more detail below). In this study, “problem domain” refers to contextual challenges leading to needs that have a direct impact on the community. Subsequently, these problems have a direct impact on the learning experiences of students. The introductory engineering course implemented in these two camps played a fundamental role in identifying these problem domains and, consequently, develop the EngStarter kit.

**Introductory Engineering Course**

The introductory engineering course was designed as an opportunity for students to access higher education coursework and gain relevant skills in the Azraq and Kakuma camps. This course covered technical concepts in electronics and programming, professional engineering skills such as teamwork, analytical skills, communication, and engineering thinking. These areas were supported under an umbrella of engineering design. The course included 24 face-to-face sessions (120 minutes in length) and took place over three months in a blended learning environment. The basic pedagogical framework used in the course consisted of a community-oriented engineering design process that supported the pedagogical strategies, assessment, and learning objectives throughout the course. The curriculum used a community-oriented engineering process grounded in social empowerment where students learned strategies to fully explore and define problems in the community, engaged in these processes by generating a wide range of solutions, and systematically created prototypes focused on real-world problems using electronic technology tools taught in the classroom.

**Research Questions**

The research aim in this paper is to add to the body of scholarly and practitioner literature regarding educational technologies in engineering education. This research also provides insight about the approach to engineering education in refugee settings beyond technology as a simplistic solution. The findings collected in this study will be used to foster discussion about the design and development of education technologies for emergencies and their impact within and outside of classrooms. We examine in this paper the development and implementation of an educational technology kit informed by two years of research and implementation of engineering classes in Azraq and Kakuma. Therefore, this paper describes the development and testing of the EngStarter Kit by addressing the following research question: *What factors shaped the development of an engineering learning kit in refugee camps, and how?*

**Theoretical Literature Review**

It is first worth noting that a handful of writers have already studied education in the context of emergencies. Tauson and Stannard (2018) thoroughly built an understanding of technologies for teaching and learning in crisis or displaced settings. Burde, Kapit, Wahl, Guven, and Skarpeteig (2017) reviewed the key conceptual frameworks that shape education in emergencies and how educational programs in these settings affect access, learning, and protection. According to their findings, education in emergencies needs to consider intervention to help mitigate anxiety, depression, or trauma in these circumstances. Consequently, these emotional aspects play an important role in the students’ academic outcomes. Therefore, more than intellectual development, education in emergencies needs to address well-being and mitigate conflict.

Emotional stress reveals a variety of factors that affect learning, academic achievement, and mental health (INEE, 2018; Shonkoff, Boyce, & McEwen, 2009); therefore, linking this study with cognitive load theory (Sweller, 2011) can help with the task of how pedagogy and curriculum can deal with cognitive overload when learning in fragile settings. The fundamental principle of this cognitive theory deals with the quality of instructional design and its attention to the role and limitations of working memory (Sweller, 2011). Thus, concerns of
the quality of instruction and students’ achievement can lead to practices for reducing the effects of the extraneous and germane load (Sweller, 1994). Central to understanding this cognitive capacity is the idea of instructional procedures that lead to knowledge and skills development.

The literature we build on also looks beyond pedagogical factors. While engineering education is strongly supported by the teaching and the deployment of technology in classroom settings (Barakos, Lujan, & Strang, 2012; Clark & Mayer, 2011; Minuto, Pittarello, & Nijholt, 2015; Nicaise & Barnes, 1996), considering the impact of technology in the society is important to guide new opportunities related to community driven technologies. Thus, science and technology studies (STS) as a field provides insights as it tries to explain technology and science as complex structures with societal influences (Martin, Nightingale, & Yegros-Yegros, 2012). This consideration where technology development can no longer be separated from society and environment development leads our use of co-production theory (Jasanoff, 2004) which will be used to evaluate the role of technology in complex humanitarian settings to advance and build peace and stability.

**Project Design and Implementation**

**Overview and Background**

Launched in 2016, the introductory engineering course first offered in Azraq and initiated in the following year in Kakuma provided a unique opportunity to understand local constraints as well as to receive students’ feedback in terms of their experiences with educational technologies. Our team experienced numerous difficulties related to existing tools to teach electronics and programming as they related to local challenges. For example, the classrooms often lacked electricity, and students often complained about limited access to electronic tools after each class session. While our pedagogy and curriculum were designed to respond to these constraints, providing contextually aligned tools plays an important role to achieve our learning objectives. In light of these challenges, our team investigated opportunities to create an education tool to help us to achieve our learning objectives. Since our curriculum was mostly grounded in community development, our initial approach was creating an educational kit that could respond to different problem domains, as well as to enable community development by targeting water, food, and energy problems in the camp. This research process led to the creation of the EngStarter.

**Hardware and Software Development**

EngStarter is an open-source hardware educational kit designed to provide students with the necessary tools, instruments, and open educational resources to build real-world solutions to their problems while learning fundamental concepts of electronic circuits, programming, and internet of things. By reproducing these applications through EngStarter, students can measure environmental variables through sensors attached to the systems, measure circuit efficiency, analyse physical constants, and examine potential applications beyond what is offered in this educational kit. After replicating the pre-designed projects, students can use the same tools and components to conceptualize and implement further applied engineering solutions.

The EngStarter integrates existing electronic sensors and open development boards through a new design. These technologies consist of Arduino™ and Raspberry Pi™ development boards, sensors, actuators, electronic components, and connectivity modules. Each kit contains basic components and sensors to build solutions for the problem spaces of water, food, and energy. The research team also provides basic codes, libraries, and tutorials to facilitate the project integration and rapid prototyping. The sensors and connectors are color-coded and reusable so that students can easily identify the correct way to connect each sensor in the circuit board and try different configurations with the same components. Students can build different applications using the same kit by following basic multimedia explanations that are available online and offline to support educators and guide students to master difficult electronic concepts.
Mobile Application

Recent studies explored mobile technology in refugee camps to enhance and enable education in emergencies (Dahya & Dryden-Peterson, 2017; Debsu, Little, Tiki, Guagliardo, & Kiton, 2016; Kleine, 2013). The EngStarter kit uses MIT App Inventor (Looney, 2014), an open-source software for mobile app development as its main platform to develop mobile applications and support existing trends in democratizing computing (Wolber, Abelson, & Friedman, 2015). This app development toolkit has been used in a broad range of applications and among differing levels of education in programming and electrical engineering (Al-Rubaye, Van den Bossche, & Raad Farhood, 2017; Dolgopolovas, Jevsikova, & Dagiene, 2018; Francese, Risi, Tortora, & Tucci, 2016; Xinogalos, Satratzemi, & Malliarakis, 2017). These applications are yet another way to make meaningful content and introduce students to cutting-edge technologies. Thus, the EngStarter mobile application adds an inclusive way to introduce IoT to students by providing a meaningful application to help students utilize and apply mobile technology to develop their community. The system is easily customizable, and students can modify the application to respond to their specific needs by using visual block language (see Figure 1).

![Figure 1. A sample of the visual block language](image)

Socially Relevant Applications

The ideas of social empowerment (Breunig, 2016; Giroux, 2007) and sustainable development (Brauer, 2013; Lucena et al., 2010) can be related to community development where technology is often seen as fundamental to advance and build societies. In other words, technology and technological knowledge are an inevitable feature of modern societies (Miller & Wyborn, 2018). However, while technology plays a crucial role in community development and demonstrates a particular influence on community, human value, and sustainability (Miller & Wyborn, 2018), a large population from marginalized and displaced communities do not have access to these technologies. Thus, the EngStarter was designed to democratize and introduce technology tools that support curricula in these fragile settings. EngStarter is also socially driven in that it demonstrates to students different ways that technology can help them to solve local problems and foster sustainability. The EngStarter can help educators to introduce problem-based learning in emergencies by using the kit to scaffold important electronic and programming principles and help students to understand how sensors and actuators can interact with the physical world. The EngStarter can also serve as a tool for students practicing fundamental engineering concepts while they focus on problems in society.

Preliminary Results

The main objective of developing the EngStarter was to offer a meaningful and contextually relevant technology tool to teach electronics and programming in emergencies. The educational kit contains sensors and electronic components that can be easily customized and programmed to real-world problems in communities in emergency contexts. These kits can be used for further applications besides the basic use in introductory engineering courses. For the purpose of this work-in-progress study and alignment with our
research question, the results to date are presented in Table 1 as factors that motivated aspects of our educational kit and our response to these constraints within this kit.

Table 1. EngStarter response to problems by domain in Azraq and Kakuma camps

<table>
<thead>
<tr>
<th>Domain</th>
<th>Problem Addressed</th>
<th>EngStarter solution characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Infrastructure</td>
<td>Unreliable power</td>
<td>3Hrs run time (internal battery)</td>
</tr>
<tr>
<td></td>
<td>Internet limitation</td>
<td>Instructions, manuals, and video tutorials available offline in the computer station embedded in the kit</td>
</tr>
<tr>
<td></td>
<td>Dusty environment</td>
<td>Individual cases with magnetic connections to protect against dust</td>
</tr>
<tr>
<td></td>
<td>Lack of space for storage</td>
<td>Easy component storage in each kit using color-coded labels</td>
</tr>
<tr>
<td></td>
<td>Maintenance cost</td>
<td>Open-hardware with replacement parts for easy repair and DIY architecture that reduces the product cost</td>
</tr>
<tr>
<td>Education</td>
<td>Student-centered tools</td>
<td>Research-driven technology emerged from students’ feedback and addressed to engineering education</td>
</tr>
<tr>
<td></td>
<td>Student engagement</td>
<td>Community-oriented applications foster students’ engagement</td>
</tr>
<tr>
<td></td>
<td>Lack of quality in STEM programs in refugee camps</td>
<td>Designed to facilitate conceptual and practical understanding of electronics and programming fundamentals</td>
</tr>
<tr>
<td></td>
<td>Equipment mobility within the camp</td>
<td>A laboratory in a box, users can carry the entire set of equipment in a single storage box</td>
</tr>
<tr>
<td>Social Empowerment</td>
<td>Lack of opportunities to address community well-being</td>
<td>The kit enables students to create solutions targeted to community needs</td>
</tr>
<tr>
<td></td>
<td>Relying on donors to address water, food, and energy problems</td>
<td>Kit applications target problems that still rely on donations and international aid</td>
</tr>
<tr>
<td></td>
<td>Independent study</td>
<td>Intuitive layout and hardware that enable students to comprehend the kit and their application by themselves</td>
</tr>
<tr>
<td></td>
<td>Professional development</td>
<td>DIY kit enables students to use the kit for learning purposes, and modular architecture allows users to build stand-alone applications</td>
</tr>
</tbody>
</table>

The testing phase has begun in refugee camps where students are using our prototypes for preliminary tests and project development. In Figure 2, we present an example of the integrated concept in the kit that enables students to build practical solutions, such as a solar-powered weather station for learning purposes built in Azraq camp, Jordan.

Figure 2. Engineering kit (left side) and solar-powered weather station (right side)

The initial two years of the course led to the development of the EngStarter. The current phase consists of testing the application of the kit in two different camps. In doing so, we intend to validate our assumptions and evaluate the impact of this new technology within the course by tracking different constructs that will be collected through semi-structured interviews, surveys, and students’ artefacts. We also intend to develop a participatory approach to test and validate the social contribution by integrating the local community into
our development process, as well as evaluating its robustness under harsh conditions given the nature of refugee camps.

**Preliminary Conclusion and Future Research Plan**

Over the last two years, the research team has been developing and delivering undergraduate engineering courses in refugee camps. Such experiences offered a unique background and understanding of the needs and constraints in refugee settings. The EngStarter emerged as one potential solution to be included in future courses as a technology tool to encourage and motivate students to learn engineering concepts while they create solutions addressing real problems in their community.

Although the kit is still in its design and testing stage, the preliminary findings and working prototype offer a significant contribution to the literature in terms of its real-world lens focusing on the existing problems and challenges in refugee camps. Existing projects that are currently running in refugee camps can take advantage of our recommendations as insights to improve the tools used in similar emergency settings. Additionally, this study opens a wide range of opportunities to explore similar principles in other disadvantaged communities where students and communities experience similar conditions, such as slums, informal classrooms, and poor settlements.

This study also opens a range of industrial applications for community-driven development technologies. In order to test and validate our assumptions, the next step consists of implementing the kit in our existing courses where we will collect data related to user experience, physical robustness, and pedagogical and real-world impact. The data will be collected through surveys, interviews, videos, and data loggers that are included in the kit. Currently, we are manufacturing kits that will be shipped to the Azraq camp and the Kakuma camp. Subsequently, these kits will be tested by a focus group and will report their experiences, challenges, and opportunities for improvement.

**References**


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Development of Student Autonomy through Flipped Classroom Methodology in Probability and Statistics

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Abstract: In this article, we present the results found when comparing three different methodologies (flipped, flipped with more intensity per day and traditional) applied in a course entitled Probability and Statistics I offered by the Engineering School. We found significant differences in the means of statistical inference final exam results, where the flipped methodology generated the best results. We also found significant differences in the variances of the final exam scores by subject, where the flipped methodology with more intensity generated the least variance.

Student perceptions of the course were analyzed using surveys conducted at the end of the semester, showing that students in the flipped methodology group felt that the course was useful, that they had learned more, that they had developed a more autonomous learning process, and that the methodology used had facilitated their learning process.

Context
Since 2015, teachers of the Probability and Statistics I (P&E I) course given at the School of Engineering at Los Andes University have redesigned teaching methodologies traditionally adopted for the course to i) shift the teaching paradigm toward a focus on fostering learning rather than merely teaching Bonk & Graham (2006); ii) to encourage student autonomy by encouraging them to become self-learners; iii) to enhance levels of interest, participation and motivation; iv) to integrate the use of information technologies to facilitate the learning process Lucke et al (2017); and v) to achieve lifelong learning Bernal & Castillo (2017).

The redesign P&E I course was developed through the Redesign of Engineering Courses 1 (REDINGE1) Project, an initiative led by the School of Engineering. Through the project, the course was redesigned in two respects: i) in terms of curricular features, where the course structure was rearranged based on four fundamental concepts related to the requirements of basic engineering training; and ii) in terms of instructional, contextual and reorientation features, where active pedagogy through the use of a flipped classroom was adopted Galvis et al (2017). In a flipped classroom, unlike when using the traditional methodology, class content is delivered to the students through the use of videos, readings and interactive presentations, and class time is used to apply and reinforce concepts through exercises and active learning methodologies Connor (2014). In a flipped classroom, it is possible to observe three moments in which a student must face different challenges and objectives: 1) before class, while preparing basic level material; 2) during class, when being evaluated on the prepared material, when reviewing principal concepts and when completing exercises of different levels; and 3) after class, when attending supplementary sessions.
P&E I is a mandatory course in the curriculum of all Engineering programs provided at the University. On average, 550 students take the course every semester, and they can choose to take it in their fourth, fifth or sixth semester depending on their specific program. Every semester, nine to ten lecture sections are offered, with 50 to 80 students assigned to each section and with 19 supplementary sections, each including an average of 35 students. Supplementary sessions are not mandatory and are designed as tutorial classes in which an engineering Master's student helps P&E students complete more complex probability and statistics exercises.

From 2015-II to 2018-I, 3 of the 10 sections offered used the intensive flipped methodology (IF), with only one weekly session of three hours; the other 7 sections used the traditional methodology (T), with two weekly sessions of one hour and twenty minutes each. In the 2018-II semester, we increase the number of sections that use the flipped methodology in concordance with the results provided by Bernal & Castillo (2017). In 2018-II, 3 sections used the intensive flipped methodology; 2 sections used the regular flipped (RF) method, with two weekly sessions of one hour and twenty minutes each; and the other 5 sections used the traditional methodology. Students randomly enrolled in classes of differing methodologies.

**Research questions**

Major problems related to teaching P&E in engineering relate to students' lack of interest in these subjects and to a lack of autonomy in their learning process. Additionally, students often do not view the course material as relevant to problems of modern engineering. To address these issues, we adopted three different strategies. The first involved changing the teaching paradigm adopted by introducing a flipped classroom methodology into the course material; we expected to mitigate the described problems because: i) in completing exercises, students were expected to understand how probability and statistics can be applied to solve modern engineering problems; ii) as students would be required to review concepts using videos and/or readings, they were expected to become more autonomous in their learning process; and iii) by challenging students to solve more complex problems in class, students were expected to become more interested in the issues discussed. The second strategy involved introducing more intensive classes each week, where students attended one class of three hours per week rather than two classes of one hour and twenty minutes per week. We expected the students' academic performance to improve as a result of the intensive classes due to being given more time to solve problems with their professors. The third strategy involved introducing supplementary sessions in which students were required solve more complex probability and statistics problems. We expected students completing the supplementary sessions to attain higher levels of academic achievement and to be more autonomous in their learning process.

Based on that described above, a number of interesting questions are posed. Does the methodology used in class have a positive effect on student learning, motivation, autonomy and critical thinking development? Do intensive classes have more positive effects on academic achievement than regular classes? Do students who attend supplementary sessions enjoy a higher level of academic achievement?

**Theoretical framework**

Multiple empirical studies have been conducted on the effectiveness of flipped classrooms, some of which show evidence of enhanced learning, while others do not report such benefits. Comber (2018) found that robust evidence is still lacking on the effectiveness of the methodology used and on how the methodology employed contributes to learning. According to Keer (2015), studies evaluating teaching methodologies adopted in the field of engineering have generated results on two areas: i) academic performance and ii) perceptions of courses.
With respect to students' academic performance in flipped classrooms of engineering, Yelamarthi et al (2015) compared the traditional methodology with the flipped classroom approach in relation to course on digital circuits and found significant differences between the two methodologies. Lamley (2013) compared flipped and traditional classes applied to a thermodynamics course and observed a significant increase in project, homework and final exam scores from the flipped classroom. Lumley also importantly found improvements to be perceived in classes with few students (less than twenty students) and noted that the same results would not be achieved from larger classes.

To evaluate student perceptions of flipped classrooms, some studies have used questionnaires, while others have used interviews. Lori (2015) analyzed student perceptions of the flipped classroom approach applied to a college algebra course. The results showed that the students felt that in the flipped classroom they were given more time to ask questions in class and that they felt more confident in their abilities to learn mathematics. Pang (2014) found 85% of sampled students to be interested in the flipped classroom methodology, as the approach allows for more face-to-face interaction with teachers. Gloria et al (2014) designed a flipped methodology for a Circuits I course. To evaluate if the flipped classroom approach has a positive impact on student perceptions of a course, they conducted a survey including questions with different affirmations presented on a Likert scale, and they found 87% of the students to agree or completely agree with the statement "I prefer to do work in class," while 85% of the students agreed or completely agreed with the statement "I prefer the format of this class compared to the traditional lecture format." Croix (2014) designed a flipped classroom methodology for a control course. To evaluate student perceptions, a survey was carried out, revealing that the majority of the students would prefer a flipped methodology course.

**Methodology**

As we are interested in comparing three methodologies based on academic performance and perceptions of a course, we conducted a statistical analysis of a final exam and another statistical analysis of course evaluation surveys. Table 1 and Figure 1 present some descriptive statistics on the 2018-II course.

![Figure 1: 2018-II course description](image)

Table 1: 2018-II course description

<table>
<thead>
<tr>
<th>Methodology</th>
<th>No. Sections</th>
<th>No. Students</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular Flipped</td>
<td>2</td>
<td>143</td>
</tr>
<tr>
<td>Intensive Flipped</td>
<td>3</td>
<td>118</td>
</tr>
<tr>
<td>Traditional</td>
<td>4</td>
<td>262</td>
</tr>
</tbody>
</table>

As is shown in Figure 1, more students failed or dropped the course when the traditional methodology was used than when the other methodologies were used. Overall, more students had enrolled in the course adopting the traditional methodology.

The final course exam evaluating the most important subjects was used as an approximation of knowledge retention. The same final exam was given to all students in the studied semester. We used questions given in previous semesters to improve the reliability of the test. Once the test was given, for each question, the reliability was analyzed using Item Response Theory (IRT), and questions not showing strong levels of reliability were removed from the analysis. Table 2 and Figure 2 present characteristics of the final exam given in 2018-II.
Figure 2 shows that the median RF for the final exam was greater than those of the other methodologies. We also found differences in the variance of final exam scores across the studied methodologies.

**Student performance**

To identify potential differences in the means of final exam scores across the three methodologies, we used a linear regression model where the dependent variable was the score on the final exam and where independent (explanatory) variables included the methodology used, the number of times that a student had attended supplementary sessions during the semester, and whether a student was repeating the course or not.

\[
FE = \beta_0 + \beta_1 IF + \beta_2 T + \beta_3 Supplementary + \beta_4 Rep + \epsilon
\]

From the described model, we did not find any significant differences among the three methodologies. As we recognized that differences may be found if questions given on the final exam were classified under different subjects, we classified the final exam questions based on the 5 central subjects of the course. Each question on the final exam was associated with an objective (there are 17 objectives) and subject of the course. Table 3 presents the association between subjects and objectives of the final exam.

The mean and standard deviation of the final exam scores by subject and methodology are shown in Table 4.
Table 4: Final exam scores by subject

<table>
<thead>
<tr>
<th>Probability</th>
<th>Random Variables</th>
<th>Joint Random Variables</th>
<th>Statistical Inference</th>
<th>Statistical Models</th>
</tr>
</thead>
<tbody>
<tr>
<td>Regular</td>
<td>0.614</td>
<td>0.537</td>
<td>0.542</td>
<td>0.803</td>
</tr>
<tr>
<td>(0.308)</td>
<td>(0.279)</td>
<td>(0.213)</td>
<td>(0.241)</td>
<td></td>
</tr>
<tr>
<td>Flipped</td>
<td>0.315</td>
<td>0.516</td>
<td>0.497</td>
<td>0.813</td>
</tr>
<tr>
<td>(0.255)</td>
<td>(0.269)</td>
<td>(0.210)</td>
<td>(0.226)</td>
<td></td>
</tr>
<tr>
<td>Intensive</td>
<td>0.493</td>
<td>0.504</td>
<td>0.535</td>
<td>0.803</td>
</tr>
<tr>
<td>(0.351)</td>
<td>(0.267)</td>
<td>(0.227)</td>
<td>(0.249)</td>
<td></td>
</tr>
<tr>
<td>Flipped</td>
<td>0.283</td>
<td>0.298</td>
<td>0.283</td>
<td>0.298</td>
</tr>
<tr>
<td>(0.238)</td>
<td>(0.254)</td>
<td>(0.238)</td>
<td>(0.254)</td>
<td></td>
</tr>
<tr>
<td>Traditional</td>
<td>0.556</td>
<td>0.504</td>
<td>0.535</td>
<td>0.803</td>
</tr>
<tr>
<td>(0.313)</td>
<td>(0.267)</td>
<td>(0.227)</td>
<td>(0.249)</td>
<td></td>
</tr>
</tbody>
</table>

*Standard deviations are shown in parentheses

Once we classified each question given on the final exam, we compared the means of final exam scores by subject and methodology using a linear regression model; the dependent variable is the score achieved on the final exam for a given subject, and independent (explanatory) variables include the methodology used and the number of times that a student had attended supplementary sessions throughout the semester. We found significant differences across the three methodologies in the subject of statistical inference. The model and results are shown in Table 5.

\[
F_{statistical\ inference} = \beta_0 + \beta_1 RF + \beta_2 T + \beta_3 Supplementary + \xi
\]

Table 5: Model for Statistical Inference

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>Stand. Error</th>
<th>t</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>0.4201</td>
<td>0.0257</td>
<td>16.288</td>
<td>0.000</td>
</tr>
<tr>
<td>Regular Flipped</td>
<td>0.0625</td>
<td>0.0299</td>
<td>2.089</td>
<td>0.037</td>
</tr>
<tr>
<td>Traditional</td>
<td>0.0570</td>
<td>0.0269</td>
<td>2.120</td>
<td>0.034</td>
</tr>
<tr>
<td>Supplementary</td>
<td>0.0151</td>
<td>0.0033</td>
<td>4.485</td>
<td>0.000</td>
</tr>
</tbody>
</table>

For subject of statistical inference, the results of the model showed that the regular flipped and traditional methodologies had a significant effect on the test results relative to the intensive flipped methodology \((\beta_{RF} = 0.0625 & p < 0.05; \beta_T = 0.0570 & p < 0.05)\). The supplementary session also had a positive effect \((\beta_S = 0.0151 & p < 0.05)\) on the test results.

To identify which methodology generated the least variability in final exam scores, we performed hypothesis tests on variances in final exam scores and on final exam scores by subject. Table 6 shows significant results of the hypothesis tests on the analysis of variance.

Table 6: Analysis of variance

<table>
<thead>
<tr>
<th>Alternative Hypothesis</th>
<th>Subject</th>
<th>Estimate</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\sigma_{RF}^2 &lt; \sigma_T^2)</td>
<td>Final exam</td>
<td>0.683</td>
<td>0.030</td>
</tr>
<tr>
<td>(\sigma_{RF}^2 &lt; \sigma_T^2)</td>
<td>Final exam</td>
<td>0.715</td>
<td>0.035</td>
</tr>
<tr>
<td>(\sigma_{RF}^2 &lt; \sigma_T^2)</td>
<td>Joint random variables</td>
<td>0.722</td>
<td>0.053</td>
</tr>
<tr>
<td>(\sigma_{RF}^2 &lt; \sigma_T^2)</td>
<td>Joint random variables</td>
<td>0.798</td>
<td>0.110</td>
</tr>
<tr>
<td>(\sigma_{RF}^2 &lt; \sigma_T^2)</td>
<td>Statistical inference</td>
<td>0.776</td>
<td>0.085</td>
</tr>
<tr>
<td>(\sigma_{RF}^2 &lt; \sigma_T^2)</td>
<td>Statistical models</td>
<td>0.779</td>
<td>0.108</td>
</tr>
</tbody>
</table>
The intensive flipped methodology (IF) presented less variability in final exam scores for courses on joint random variables, statistical inference and statistical models. The results also showed no significant difference between the variances of the regular flipped (RF) and traditional (T) methodologies.

Our findings show that students will achieve stronger results on final exams when they attend supplementary sessions and that the regular flipped methodology generates better results on final exams in the subject of statistical inference than the other methodologies.

Student perceptions
To measure student perceptions of the flipped classroom methodology, course evaluations developed by the university’s School of Education were analyzed. Students were asked to provide their views on the enhancement of their autonomy, coherence and critical thinking as well as feedback on the teacher’s responsibilities in class. We analyzed 160 surveys pertaining to the flipped methodology (regular or intensive) and 300 surveys on the traditional methodology. Figure 3 presents a word cloud illustrating responses given to the question “what positive aspects of the course can you highlight?”

Figure 3: Responses to the question “what positive aspects of the course can you highlight?”

Figure 3 shows that the words "interesting" and "useful" were those most frequently used by the students in reference to both methodologies. From these results, we can conclude that when adopting the two methodologies, these issues are of interest and useful for students’ professional development. The terms "learning," "methodology", “help” and "organized" are cited more frequently among students of the flipped classroom than among those subjected to the traditional methodology. Table 7 shows the results of a hypothesis test on the frequency at which the most common words are used to refer to the different methodologies. Although the terms "learning", “methodology” and “help” appear more frequently in reference to the flipped methodology than in reference to the traditional methodology, no significant differences were found.

Table 7. Hypothesis test on the frequency at which terms are used to describe the studied methodologies

<table>
<thead>
<tr>
<th>Word</th>
<th>Alternative Hypothesis</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Useful</td>
<td>( \mu_F - \mu_T &lt; 0 )</td>
<td>0.16</td>
</tr>
<tr>
<td>Interesting</td>
<td>( \mu_F - \mu_T &lt; 0 )</td>
<td>0.32</td>
</tr>
<tr>
<td>Learning</td>
<td>( \mu_F - \mu_T &lt; 0 )</td>
<td>0.62</td>
</tr>
<tr>
<td>Topics</td>
<td>( \mu_F - \mu_T &lt; 0 )</td>
<td>0.23</td>
</tr>
<tr>
<td>Help</td>
<td>( \mu_F - \mu_T &lt; 0 )</td>
<td>0.57</td>
</tr>
</tbody>
</table>
We may thus conclude that students view the topics explored as interesting and useful not only for their professional development but also for their lives in general.

To evaluate student perceptions regarding their development of autonomy and critical thinking, three questions on this issue were included in the course evaluation. We analyzed 71, 87 and 153 responses referring to the intensive flipped, regular flipped and traditional methodologies, respectively. The students rated their level of agreement to the statements given on a Likert scale. Figure 4 shows 95% percent confidence intervals for the percentage of students who strongly agree with, agree with, are neutral to, disagree with or strongly disagree with the statement “The teacher raises questions that further explore the principles taught in class.” The majority of students, regardless of the methodologies they were subjected to, strongly agreed with this statement. Even though there are no significant differences among the methodologies, 64.4% of the students subjected to the regular flipped methodology strongly agreed with the statement while this percentage was only 54.9% and 52.3% for the intensive flipped and traditional methodologies, respectively.

“The teacher raises questions that further explore the principles taught in class.”

Figure 4. 95% CI for the statement “The teacher raises questions that further explore the principles taught in class.”

Figure 5 shows 95% percent confidence intervals for the percentage of students who strongly agree with, agree with, are neutral to, disagree with or strongly disagree with the statement “The teachers encourage their students to review their work and to learn from their mistakes.” The figure shows that most of students, regardless the methodology that they are exposed to, strongly agree with this statement. We also found a significant difference between the methodologies where for the regular flipped methodology a higher percentage of students strongly agree with this statement relative to those subjected to the traditional methodology.
The teachers encourage their students to review their work and to learn from their mistakes.

Figure 5. 95% CI for “The teachers encourage their students to review their work and to learn from their mistakes.”

Figure 6 shows 95% percent confidence intervals for the percentage of students who strongly agree with, agree with, are neutral to, disagree with or strongly disagree with the statement: “The teacher invites us to critically analyze the situations and problems presented in class.” The figure shows that the majority of students, regardless the methodology they were subjected to, strongly agree with this statement. Although we find no significant differences between the methodologies, 66.3% of the students subjected to the regular flipped methodology strongly agree with the statement while the percentages are valued at only 55.2% and 60.0% for the intensive flipped and traditional methodologies, respectively.

The teacher invites to critically analyze the situations and problems presented in class.

Figure 6. 95% CI for “The teacher invites to critically analyze the situations and problems presented in class.”

From these findings, we can conclude that the students developed their sense of autonomy and critical thinking skills through the course. Moreover, the percentage of students
experiencing this skill development was found to be significantly higher for the regular flipped class.

Conclusions

An analysis of the results of applying the three tested methodologies shows a significant difference in statistical inference final exam scores. We also found the variance in the overall final exam scores and in the final exam scores of joint random variables, statistical inference and statistical models subjects to be lower for the intensive flipped class than for the class adopting the regular flipped and traditional methodologies. We also found supplementary sessions to have a significantly positive effect on the test results. We found that students found the courses delivered interesting and conducive to their professional development. We also found that regardless of the methodology used, students strongly agreed that such a course could help them develop a sense of autonomy and critical thinking skills. We found significant differences in the percentage of students strongly agreeing with the statement “The teachers encourage their students to review their work and to learn from their mistakes” where the regular flipped methodology generated better results.

In conclusion, it is clear that the regular flipped methodology generates better results in terms of academic achievement and in encouraging autonomy and critical thinking. These results are both suggestive and align with broader findings from the available literature.

This study presents some limitations. First, the study was based on a limited number of control variables; therefore, important information that may affect academic achievement and perceptions was not considered. Second, while we measured academic achievement only in terms of final exam scores, other academic activities may be used to measure academic achievement as well. Third, class times and attendance may also affect academic performance. In future work, we must continue to undertake formal studies: i) that review the impact of the flipped methodology on lifelong learning by monitoring courses seen after P&E, ii) that review the development of soft skills at a deeper level, and iii) that measure the impact of the different activities of flipped methodologies such as quizzes and exercises.

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Trialling a problem-solving engineering learning environment

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Abstract: In the face of increasingly technologised 21st century industrial contexts, engineering faculties are challenged with ways to enable effective engagement with the practices and tools of the profession. Given the national mandate to increase enrolment and success in tertiary engineering qualifications so as to address local, national and international Sustainable Development Goals (SDGs), this paper presents the research-informed design and piloting of an innovative, relevant and responsive learning environment. The paper draws on qualitative and quantitative research data from a review of over 50 engineering problem-solving case studies across engineering sectors, as well as survey data from a pilot study on an open-plan, situated learning, project-based engineering training environment. The research employs a theoretically-informed instrument from Legitimation Code Theory - Specialisation - to graphically demonstrate the relationship between forms of engineering knowledge practices and the physical engineering learning environment.

Introduction

One of the key challenges faced by engineering educators globally is how to address industry complaints that graduates do not have the required ‘soft’ and technical skills. An international survey of over 40 000 employers across 42 countries found 34% of respondents citing ‘lack of required technical skills’ as the key reason for being unable to appoint graduates (manpowergroup.com, 2015). Efforts to address such concerns have included the adoption of a range of work-integrated learning (WIL) strategies into the curriculum, from problem-/project-based learning to situated or simulated learning, and even to learning in actual workplaces for specified periods of time. Successful forms of the WIL modalities are reliant on the availability of human and technical resources (Mutereko & Wedekind, 2015), and many of the ‘victory narratives’ are indeed small-scale and well-resourced initiatives. In South Africa – the site of the research presented in this paper – there are complex challenges to enabling effective practical learning, particularly with regard to workplace learning, from poor management of work placement processes to lack of appropriate mentorship (ibid.). The key challenge, however, may lie in the engineering education community’s lack of problematisation about what exactly it is that forms of WIL are meant to accomplish.

There is no question about the validity of theory-practice bridging in engineering professional education – it is mandated by all signatories to the three accords governing engineering qualification and professional levels. The International Engineering Alliance (IEA, 2013) sets out a holistic range of descriptors designed to frame the required competencies for the three engineering levels, encompassing categories such as knowledge, skills and attributes. This echoes Barnett’s (2000) description of the curriculum for supercomplexity as simultaneously...
having epistemological, praxis and ontological dimensions. The IEA’s overarching definition states that engineering is “an activity that seeks to meet identified needs of people and societies by the purposeful application of engineering sciences, technologies and techniques to achieve predicted solutions that use available resources efficiently, are economical, that manage risks” (Hanrahan, 2014, p. 109). As such, curricula are designed around opportunities to train towards and assess the achievement of Graduate Attributes, the primary one being the ability to solve problems at three levels: well-defined (technician), broadly-defined (technologist) and complex (engineer). This act of problem-solving is intended to encompass the sciences, technical skills and ‘soft skills’ such as communicating effectively with an engineering-related audience, understanding the impact of engineering activity, team work, self-regulated learning and professional ethics. These so-called soft skills are deemed the skills most needed by employers (Cappelli, 2014), and are routinely curriculated as separate subjects, as are many of the practical curricular components.

The dilemma facing engineering educators who introduce relevant technologies into their curricula is that in an age of increasing sociotechnical and technological complexity, the dynamic developments in hardware and software mean that much of the practical technology-dependent teaching in the engineering education space may well be redundant once the graduate enters the industrial space (Felder, 2012). Furthermore, the nature of engineering workplaces of the 21st century is diverse and “the range of engineering practice and…possible applications is large” (Hanrahan, 2014, p. 110). It is not feasible to introduce undergraduates to all types of technologies and the full range of contextualised application (Wolff, 2015). How then should educators realistically enable the holistic development of the required competencies?

The purpose of this paper is to illustrate a social realist approach to training problem-solving engineering practitioners, based on a theorised view of engineering practice drawn from empirical, industry-based, problem-solving research over the past decade. The paper makes use of analytical instruments from Legitimation Code Theory (LCT) (Maton, 2014) to interpret the industrial research findings and analyse student feedback on their experience of an explicitly designed problem-solving learning environment which has been piloted over a four-year period at an independent engineering training centre.

Conceptual framework

The research on which this paper is based draws on a number of theorists from social realism to the decision sciences. The fundamental premise is that forms of disciplinary and practical knowledge have different properties, which have implications for teaching, learning and application. There are numerous typologies that attempt to differentiate between different knowledge practices, more often than not in binary form, such as theory-practice, principles-procedures, abstract-concrete, and so on. Muller (2009) differentiates between curricula that are dependent on concepts and those that are more contextually focussed, such as vocational or occupational qualifications. The conceptual-contextual continuum is routinely used to differentiate between the three engineering qualification levels: engineer (Bachelor of Engineering), technologist (Bachelor of Engineering Technology/Advanced Diploma in Engineering) and technician (Diploma in Engineering). The question facing educators across these qualifications is always how much theory and how much practice?

Gamble (2018, p. 39) talks about the principled or procedural logics of problem solving in relation to the end result: “The logic of work is procedural where problem solving is standardised and the end result pre-defined. The logic of work is principled where problems are novel and unpredictable and ‘general principles’… guide specific problem solving”. Any experienced engineering educator will point out that there are procedures entailed in the application of any of the laws (principles) of natural science, and principles entailed in the Standard Operating Procedures of a workshop or factory, for example. The binary differentiation does not help to make curriculum decisions for the professions, and Engineering has always occupied an uncomfortable space between these poles.
Engineering students and practitioners (whether at professional engineering level or technician) engage with both principled and procedural forms of knowledge and work. We suggest that not only are these not mutually exclusive, but that they are entirely interdependent. Herbert Simon (1996) stresses the importance of distinguishing between the inner and outer environments of any artefact. Using examples such as flight (airplane and bird) and clocks (weight-driven and battery-driven), he demonstrates that, for example, “we can analyze [an artefact] by the methods of natural science without any particular attention to purpose or adaptation” (ibid., p. 7). In other words, we can insulate the inner principles of the artefact from the outer environment, much as we do in the traditional silo curriculum. However, if “the properties with which the inner environment has been endowed are placed at the service of the goals in the context of the outer environment” (ibid., p. 10), 

*it is the outer environment which “determines the conditions for goal attainment”* (ibid., p. 11).

Given that the engineering practitioner is required to solve problems at the interface between nature, society, technology and science (UNESCO, 2010), it is essential that they are enabled to link the theories and practices of the ‘inner’ disciplinary environment to those of the outer contextual environment in order to attain the ‘goal’ of actually solving a problem. A consistent employer complaint is the inability of students to ‘apply theory’ (Griesel & Parker, 2009). We suggest that this may be exacerbated by idealised or decontextualized ‘practicals’ in engineering curricula, which differ significantly from problems encountered in real environments. Wheelahan (2009) has argued extensively that practice-based training runs the risk of being trapped in particular contexts (in other words, a particular outer environment), and denies students’ access to powerful, disciplinary forms of knowledge (which constitute the ‘inner environment’ of any artefact). “Students need access to the disciplinary system of meaning as a condition for using knowledge in contextually specific applications” (Wheelahan, 2009). It is our responsibility as engineering educators to ensure that we enable our students to meaningfully access the ‘know-why’ (Muller, 2009) that underpins any ‘know-how’, particularly in rapidly evolving, technologically-dependent professions. The purpose of education is not merely to produce ‘workers’, rather “a qualification is intended, primarily, to enable access to higher level studies and to "help guide entry into the workforce" (Wheelahan & Moodie, 2018, p. 137).

### Theoretical instruments

One way to overcome binary dichotomies is to adopt a relational approach. Legitimation Code Theory (LCT) has emerged as a useful framework for theorising, analysing and enacting ‘knowledge practices’ from a ‘both/and’ perspective, as opposed to an either/or one (Maton, 2014). If we are to understand the relationship between theory AND practice, then we need an instrument to help us differentiate between phenomena upon which theories are based and the approaches to those phenomena. Several LCT dimensions have been used in education (and beyond) to examine meaning-making practices (Semantics), what counts as legitimate in a field (Specialisation codes), kinds of ‘knowers’ (Specialisation: Social Relations), and kinds of knowledge (Specialisation: Epistemic Relations).

The Epistemic Plane is about the what and how of a knowledge practice (figure 1). The vertical axis is about any phenomenon - ‘what’, and the horizontal axis is about ‘how’ we approach that phenomenon. When we have a strongly ‘bounded’ phenomenon that everyone agrees on, as well as fixed methods to work with that phenomenon – such as in the natural sciences - we talk about needing a ‘purist insight’. When it does not matter what the phenomenon is, but there are fixed methods (such as mathematics or the scientific method) we talk about needing doctrinal insight. When the phenomenon is clear, but there are multiple ways to approach it, we need ‘situational insight’ – in other words there are multiple possibilities determined by the particular situation. This applies to all technologies. When nothing is clear, we talk about ‘no’ insight, or we are not talking about knowledge itself, but people in contexts – referred to as ‘knower insight’. Each of these ‘insights’ represent ‘ways of thinking and doing’, kinds of ‘codes’. These codes were loosely translated into principles,
procedures, possibilities, and ‘people & places’ to enable accessibility for industry participants and engineering academics (Wolff, 2015) on a PhD study. This paper uses the Epistemic Plane to illustrate 1) how engineering practitioners in real world industrial sites link theory and practice, and 2) how students perceive an integrated learning environment designed (using the Epistemic Plane) to develop engineering problem-solving competencies.

Figure 1. Annotated epistemic plane based on Maton, 2014, p. 177

**Empirical studies on how engineers work**

The LCT Epistemic Plane was the primary analytical tool used on two NRF-funded postgraduate research projects looking at how engineering technicians and technologists solve problems in real industrial sites. The research differentiated between the inner environment of the artefact at the heart of the identified technical problem, and focused on how the practitioners drew on mathematics, physics and logic-based thinking. The outer environment was defined as constituted by the problem solver, the physical environment (nature, scale and structure of the company in question) and the problem context. Participants were interviewed at their workplaces in relation to the technical problem they had identified during a phase 1 online survey. The audio and video-recorded interviews were transcribed verbatim onto a spreadsheet and coded to reflect direct or implied mathematics, physics, logic-based (software, programming) and contextual references. The key analysis, however, was ‘how’ practitioners spoke about the problem, and what insight was demonstrated across the problem-solving process stages: 1) Approach, 2) Analysis, 3) Identification of cause, and 4) Solution.

The transcriptions were graphically mapped onto the Epistemic Plane as summaries of the problem-solving processes in three outer environment categories: A – small, R&D environments; B – medium, modular systems environments; C – large, distributed systems, production environments (figure 2).
Key findings reveal that successful problem-solvers engage in iterative code-shifting processes, moving from one insight to another. They recognise when to take stakeholders, circumstances, principles and procedures into account, and this is reflected in the way they speak about the process. The different environments dictated preferred approaches, and most problem-solving difficulties arose from an inability to move from fixed to open-ended methods, in other words from right to left on the plane.

Figure 2. Engineering problem-solving patterns across industrial contexts

Empirical studies on how engineering students learn

Based on the empirical problem-solving research, a small, independent engineering training school adopted an open-plan, ‘code-shift’ supporting learning environment. School leavers enrol for a gap-year programme consisting of four 10-week modules, each covering the basics of mechanical, electronic and control engineering in a hands-on laboratory.

Figure 3. Integrated learning environment (ILE)
The environment (figure 3) is specifically designed as an interdisciplinary one, with mechanical and electronic students working side-by-side with coding and automation students. Facilitators do not lecture in the traditional sense; rather, they assist on a small group or one-to-one basis with the consolidation of the ‘principles’ from a purist perspective. All the curricular resources entail practice guidelines and exercises to enable regular engagement with doctrinal procedures on the equipment around the ILE. The perimeter of the laboratory is equipped with visible, dedicated technical work stations such as an electronics bench, several 3D printer stations, and a range of automation stations. In order to promote open-ended situational problem solving and knower insight, students regularly collaborate on projects and engage with industry by way of site visits, projects and panel presentations.

Impact evaluation

With the ILE designed based on the findings of the industrial problem-solving case studies (reported extensively elsewhere in the literature), the team of educators has consistently sought feedback not only on student learning, but also on their experience of the environment. The students (n=42) have a dedicated student counsellor/mentor who monitors the students’ compulsory weekly reflective logs. Students also complete a quarterly survey on the curricular and pedagogic aspects of their various courses. The school sought feedback on the environment itself, and an anonymous survey was distributed to the current students (n=18). For the purpose of this paper, the focus is on three particular questions:

1. What are the advantages of working in this kind of environment?
2. What are the disadvantages of working in this kind of environment?
3. Any other comments about the nature of the learning environment?

The survey results were analysed by the research team using what Maton (2014) terms a ‘soft focus’. The intention was to determine whether or not there was evidence of the particular Epistemic Plane ‘insight codes’ reflected in the student feedback.

Student experience of a problem-solving learning environment

The initial coding of student responses to questions 7 and 8 (advantages and disadvantages) led to the observation that most responses could be allocated to the left-hand side of the Epistemic Plane (figure 4). Students report that they benefit from having access to each other, different fields simultaneously, different inputs on their projects, and exposure to people in the world of work. A key benefit is given as ‘peer learning’, and educators at the school routinely encourage students to guide each other, as well as collaborate on projects. These activities support the development of a number of professional Graduate Attributes which do not receive as much attention at traditional institutions.

In the disadvantages section, two key themes emerge: the perception of 1) a lack of formal theoretical work and 2) the potential for distraction. This appears to speak directly to Simon’s (1996) differentiation between the ‘inner’ and ‘outer’ environments of an artefact. The two students who noted that they would like to do more science and mathematics did so in comparison to “other universities” and appear to have had experience elsewhere. They may well feel that the ‘inner’ theory is obscured by the ‘outer’ conditions, particularly given that the most significant disadvantage listed is distraction: “If you don’t have self-control you could get distracted” and “One has to be able to work with peers, by this I mean noise”. However, a number of comments support one student’s remark that “The practical aspects ready us for what we can expect out of an actual working environment”.

The key observation by the researchers was that the environment seems ideal for students who have different kinds of learning needs. One student pointed out that “The hands-on teaching helps a lot with visual learning especially perfect for students who can’t manage to study for hours long”. Another describes his/her experience in contrast to that of school:
During high school it was hard for me to concentrate and there were times I would fall asleep in class, daydream etc. I think this is was due to the fact that very little freedom was granted to us as well as we would have to keep the pace of the slowest learner, this made for a very anti-social experience. I feel like the open-plan environment really puts life back into teaching where students can express their creativity and outshine their peers if they so choose to.

**Figure 4. An epistemic mapping of student feedback on the ILE**

**Concluding comments**

In an attempt to create an environment to enable code-shifting practices between the principles, procedures, and possibilities of engineering work in relation to people and places, a survey of students who have experienced such an environment reveals far more benefits on the left-hand side of the Epistemic Plane - in other words, a greater emphasis on collaboration, peer learning, access to a broader range of possibilities. This may provide insight into responding to industry feedback on graduate inabilities to cope with more open-ended problems. In other words, if graduates are to be able to work more effectively in the real world, they may well need more exposure to open-ended problem-solving opportunities during the course of their formal studies.

On the other hand, the focus on practical, project-based learning appears to have led students to believe that they are not ‘doing theory’. This suggests they are not necessarily recognising the ‘inner environment’ (Simon, 1996) and are focussed predominantly on ‘outer environment’ conditions. Wheelahan (2009) warns us about contextually (outer environment) limiting access to powerful knowledge (inner environment). We suggest that the nature of these inner and outer environments is such that they both need to be explicitly foregrounded and strategically linked in inter-disciplinary project-based learning environments. The educators in this context would need to attend to the disjuncture.
This paper does not attempt to suggest a one-size-fits-all solution. Rather, given the challenges we face in producing the problem-solving engineering graduates so desperately required by industry, we hope to encourage educators to not only adopt alternative approaches to inducting students into the ways of being, believing, valuing (Gee, 1996) of a profession, but also to reflect on the impact of the outer environment on student learning.

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Identity in Practice: Reflections from Malaysian Women who are Practicing Engineers

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Abstract: Female representation in the Malaysian engineering workforce ranges from 46% (public sector) and 51% (private sector) and stands in marked contrast to the systematically low proportions of women working as engineers in the United States. This paper explores how female Malaysian practicing engineers view their identities as practicing engineers and how their descriptions differ from the engineering identities described by women in the U.S. Initial analyses suggest that Malaysian women engineers do not perform the same type of professional identity negotiation as their counterparts in the U.S. Our initial findings also suggest that while engineering as a field in Malaysia is gender typed as masculine, female engineers wield their professional identities to address gendered workplace challenges differently than women in the U.S. Findings presented here are part of a larger study that seeks to understand why women pursue and persist in engineering as a curricular and career choice.
Introduction and motivation

Interestingly, Malaysian practicing engineers boast approximately 46% women in the public sector and 51% women in the private engineering manufacturing, and construction work sector (MWFCD & UNDP, 2014). While there have been a handful of studies attempting to explain the high number of women in computing in Malaysia (e.g., Lagesen, 2008), there are very few studies describing women in engineering in Malaysia, and fewer still provide insights about engineering identity. On the other hand, the U.S. context and other western industrialized economies all have similarly low proportions of women working in engineering (Charles & Bradley, 2009). Despite decades of research and millions of dollars in investment, women in the United States continue to be significantly under-represented in engineering at both the undergraduate, graduate, and workforce levels. Although women graduate with approximately 20% of engineering degrees, in the U.S. many drop out of engineering practice in particular, citing factors like feeling marginalized in the engineering workplace (e.g., Seron, Silbey, Cech, & Rubineau, 2016) and a mismatch between their identities and the acceptable engineering identities in the workplace (Faulkner, 2000; Hatmaker, 2013; Atiq, Morton, Ater Kranov, Kmec, & DeBoer, 2018) contexts would benefit from study of women’s engineering identity in a space where they are well-represented.

Recognizing the salience of identity, we ask the following research questions: (1) How do Malaysian women practicing engineers describe their engineering identity? We report four themes that have emerged from our analysis that illustrate women’s identity as practicing engineers. In our discussion of each of these four themes, we provide context to respond to the question, (2) Further, how do the themes that characterize women’s engineering practice identity(ies) differ from identities described in the United States and other high income North American and Western European contexts, where much of the work on engineering identity has been focused?

Literature Review and Conceptual Framework

We contribute to the existing literature, which has thus far largely come from the perspective of the U.S. and the high-income western high-income countries, that discusses gendered identities in engineering by querying identities in engineering work for women in Malaysia. In addition to contributing to a richer, more cross-nationally and cross-culturally representative theoretical base, practical implications of this study can inform novel supports for women in engineering in numerous contexts. Our project’s high-level research aim is to understand the macro- and micro-facilitating conditions that enable the high level of participation in engineering by women in Tunisia, Jordan, and Malaysia. By understanding the conditions that make such high participation of women across engineering fields and sectors (academia and industry) possible, both interventions to support women’s participation and research into gender in engineering can be more appropriately complexified. In Malaysia, women represent a high share of engineers, including both engineers in academic institutions and industry – approximately 45% overall (UNESCO Institute for Statistics - Global Education Digest, 2008). Of related interest in the case of Malaysian women’s representation in STEM are the gender ratios in the computer science and IT sectors of Malaysian industry. According to Seymour & Hewitt (1997), women represented 65% of the students at the School of Computer Science at Universiti Sains Malaysia (USM) and 66% of the students in Computer Science and Information Technology at the University of Malaya during the academic year 2001-2002. Studies of these proportions argue that they relate to a favourable socio-political environment that supports the rearrangement of social, political, gender and ethnic identities at play in the country (Goh, 2002; Gomes & University, 1994; Kahn, 1992).

Lagesen (2005) further asserts that one possible explanation for the case of Malay women’s high representation in computer science is the historical existence of race-based policies, specifically a quota system of policies initiated in the 1970s. This quota system originated in what was controversially termed the bumiputera policy, a policy written into the constitution
that defined a special position for “Malay” or indigenous peoples. The policies include practices by which Malaysians of Chinese and Indian descent are disfavored on the grounds of race while the bumipeteras (“sons of the soil”) are constitutionally afforded special rights and privileges. What is more, these race-based politics specifically discriminated against Chinese and Indian women (Luke (2002), Lagesen (2005), Ng (1999) and Ng and Shanti (1997)). As summarized by Mellström (2009): “race becomes a more pertinent and pervasive social category than gender, and it possibly and somewhat paradoxically operates more effectively to include women than many other inclusion strategies that have tried thus far” (p.893). This statement is echoed by the work of a number of scholars of Malaysian history and culture who assert that gender politics in Malaysia has always been superseded by race (Ng & Shanti, 1997). Some of these policies continue to be debated, and changes have been made in some educational practices, yet the historical legacy of race-based politics remains influential in Malaysian culture where the ethnic label determines many social and political rights (Nagata, 1996; Liu, Lawrence, Ward, & Abraham, 2002) In such a diverse ethnoscape, one should be cautious when using Eurocentric or Western feminist lenses with regards to Malaysian women and girls. In fact, Joseph (2000) argues that most often, such analyses fail to recognize the complexity of Malaysian society.

Other scholars attribute the gender balance in technical fields in Malaysia to an occupational or sector-based gender segregation. Occupational gender segregation in Malaysia distinguishes between a political bureaucracy that is heavily male-dominated and a nationalism that reflects a more global and western corporate masculinity (Cornell, 2001). These two macro-identities stand in contrast, and Mellström (2009) concludes that the traditional relational notion of masculinity and its realization in political and social hierarchies opens space for women’s participation in the sphere of newly industrializing nation such as Malaysia.

In our study, we specifically build on work on engineering identity and two potentially competing dualities. On the one hand, (Ng, 1999) shows that professional and gender identities stand in contrast and conflict with each other. In particular, female engineer’s professional identities are not gender-neutral—they are women first, engineers second (Faulkner, 2009; Hatmaker, 2013). Specifically, Hatmaker (2013) finds that workplace interactions marginalize women’s professional identities and highlight their gender identities, a process that leads to women’s self-management of the professional impression they make on others and one that takes a substantial professional and personal toll on women impressions of them. IN this study, we investigate whether professional and gender identities for Malaysian women (hereafter professional engineers or PEs) are similarly disjoint. In addition, we query Faulkner (2007)’s competing concepts of engineering identity as “technicist” vs. “heterogenous” or “technical/social dualism”. We investigate whether we see one, both, or neither in respondents’ descriptions of their engineering identities.

Faulkner (2009) provides a helpful overview of engineering identity research, and multiple aspects of her systematic review help us situate this study. First, she notes that it is important that we specify our definition of “engineering identity” to contextualize the type of work we do. Our work bridges the gap between professional and collective perspectives on engineering identity (responding to one of Morelock’s recommendations for engineering education research). We focus on the collective definition that, according to Morelock’s review and paralleling Tonso’s (2014) categorization, delimits engineering identity in the context of broader groups of people (e.g., whole nations, cultures). Our focus group interviews and inductive analysis are used to elicit both collective definitions of who engineers are and what they do as well as illuminating variation in these collective identities. In addition, we incorporate study of the concept of professional identity, or what Tonso describes as negotiation between the professional role or field and the individual person. Morelock puts all engineering identity research that uses “frameworks” into this category, and we specifically build on two of these individual conceptions. Faulkner (2007) and Hatmaker
(2013) illustrate what Morelock categorizes as two distinct sub-definitions of professional identity, respectively: the notion that engineering identity involves an individual's perceptions of the field, their relation to it, and others' perception of them, and the idea that engineering identity is the result of an individual's actions, including their acceptance or rejection of the profession and configuration of their role in it (Morelock, 2017). We investigate these individual actions and perceptions in the context of a collective national/sociocultural case, a specific gender context, and in the context of engineers working “in practice”.

**Methodology**

These findings are part of a larger study of the micro- and macro-factors that shape women’s participation in engineering in three predominately Muslim countries. We have conducted focus groups with a total of 168 women who either study, teach, or practice engineering in Tunisia, Jordan, and Malaysia. Data for this particular study draw on focus groups with 16 practicing engineers (PEs) across different sectors of work in Malaysia. Focus group interviews were transcribed, coded, and analysed using the Constant Comparative Method (CCM). Themes and sub-themes were organized and further analysed in the context of professional engineering identity. Here, we report on themes that describe engineering identity for the Embedded Unit of Analysis for Malaysian practicing engineers.

**Data collection**

In total, 16 practicing engineers participated in data collection, in 4 focus group discussions and 5 individual interviews (because of individual preference and/or scheduling demands). Practicing Engineers (PEs) were given a semi-structured protocol of questions, most of which paralleled the protocol of questions administered to undergraduate student and faculty focus groups. These included questions about their pathway into engineering, such as “Have you ever wanted a career in something other than engineering? If so, what? What made you decide to stay in engineering?” and questions about environment and experiences, e.g., “Is your perception of engineering different now compared to when you started your career? If yes, how is it different?”. The few questions that were added specifically for PEs probed their work and their decisions to go into industry, e.g., “How did you choose a career in industry over academia/other jobs?”. Interviews were conducted in English by members of the combined US- and Malaysia-based research team. A small number of clarifications were made in Malay by the local members of the research team and these were translated prior to transcription.

**Analytic methods**

Our larger study employs two methods to analyse our information and address our research questions: (1) a case study (Yin, 2014), more specifically a multi-site case study, with three embedded units of analysis (EUA) across three higher education institutions (HEIs) in three countries; and (2) constant comparison analysis methods (CCM) in order to ensure an inductive approach and to facilitate the emergence of themes out of the data. In this paper, we focus on our CCM analysis within one particular embedded unit of analysis.

We use CCM analysis as elaborated by (Lincoln & Guba, 1985) and as specifically described by (Grove, 1988). Broadly speaking, the CCM process can be broken into four stage: (1) code units of information from the raw data (in our case, translated and transcribed interviews); (2) categorize units into meaningful groups; (3) identify patterns within and between categories; and (4) conduct member checking. At the time of writing, the first three stages have been completed for the Malaysian PE embedded unit of analysis. Member checking will be done prior to REES, with the subsequent addition of the member checkers as authors. We will continue to revise and refine themes and sub-themes, and we plan to have completed the themes, thematic map, and a first round of member checking in advance of presentation at the REES conference.
The coding, categorizing, and synthesis stages of CCM were completed by multiple researchers on our team. For each stage, the research team conducted a training led by the primary investigators (PIs). Then, two research assistants served as the primary analysts on the same sets of data, meeting frequently and reviewing codes, categories, and thematic maps to assure confirmability and dependability. In the middle and at the end of each stage, the research assistants conferred with a PI to check on the analysis. As a result of Stage 3 (prior to member checking), a thematic map was constructed. In the context of professional identity research, we identified the most salient themes.

Current results
Initial findings for this work-in-progress point towards the formation of an identity that recognizes a gendered conception of engineering in practice, including challenges associated with women in the engineering workplace. However, themes also indicate a desire for “taking on a challenge” on the part of Malaysian women in engineering industries. This desire for challenge extends to an excitement about the newness and pace of engineering work in industry. Further, we identify two themes that point towards a lack of conflict in women’s personal and professional identities as engineers. For each of the four relevant themes, we provide example quotes, and we situate the theme within relevant literature on engineering identity.

Perseverance and the need to prove themselves
The first emergent theme (including sub-themes or “clusters” as well as specific categories) related to Malaysian PEs' engineering identity was one of perseverance. A number of categories referred to women's double burden of needing to work harder than men to be accepted in the field of engineering or to be perceived as competent and capable. Practicing engineers described a need to be tough and persist through difficulty, including an initial period in her engineering work where she had to prove herself to colleagues, supervisors, and even technicians whom she supervised.

As one engineer described, she felt the need to assert her capability and strength each time she encounters a new colleague:

Respondent 1: “…Even though it’s like they’re making you in their group but then it’s like what’s wrong in a girl being strong? Isn’t it? It’s so annoying. But for now the new comers will assume me so but after I showed them that I just can do anything then they’ll be Okay fine, I don’t want to have any problem with this girl anymore.”

Despite the prevalence of women in engineering in Malaysia, gendered perceptions of the field were clearly felt by women in industry. Interestingly, the dominant response to being questioned or discriminated against was not a desire to quit engineering, but instead an eagerness to prove themselves. This dualism (managing others’ impressions of them to gain confidence and embracing this challenge) mirrors studies of engineering identity in North America. Dryburgh (1999) describes both engineering culture and engineering identity as one of a “work hard, play hard” dynamic. She finds that women’s identity navigation evolves to manage male impressions of female engineers. This management of impressions is in service to a whole identity of the profession to which women have to show their membership. However, in the U.S. this professional identity negotiation is neither described as an “initiation” phase nor as a welcome challenge, as the identity ascribed by the Malaysian PEs exhibited. Instead, in the U.S. women’s professional engineering identity negotiation is a near constant struggle.

Multiple sources of identity confirmation
The second clear theme as related to the development of Malaysian women’s identities as professional engineers was a broad and diverse array of support factors. In other words,
instead of one clear “macro- or micro-facilitating condition” that helped to develop women’s professional identities in engineering, Malaysian professional engineers describe a variety of dimensions that reinforced and confirmed their identities as working engineers. For example, PEs report clear support and positive influence from their families, sponsorship/scholarship for pursuit of engineering studies, and resonance between their strong math and science abilities and interests and their work as engineers. These multiple sources of professional identity formation and support form a robust sense of themselves as “engineers” as a professional identity (BLINDED).

Respondent 2: “Okay me, why I chose engineering because of my father. Previously my father is a worker. They do the construction area. Every time I see my father so I say, okay I want to become like him because everything he do by himself. They repair all everything, love everything so need to ask somebody, okay you do it so you can do it by yourself. So why I need to pay another person [Inaudible] if I can do it by myself. That’s why I choose engineering.”

We see, in particular, that women’s educational experience includes multiple sources of confirmatory identity formation, including scholarships, strong academic performance, friends, and teachers. The resonance of strong academic performance with women’s representation in engineering has been made in prior work on Malaysian women in STEM more broadly, as Mellström (2009) explained the overrepresentation of Malaysian women in STEM field and many other academic fields by a long standing concern than Malay women outperform men in Malaysian academia, as well as in other areas of the society. Furthermore, having a positive interaction with faculty and advisors has been found to be strongly associated with students’ choice and persistence in science and engineering and information technology related majors across national contexts (Sax, 1994). In fact, Turner, Bernt, and Pecora (2002) found that secondary school teachers in the U.S seem to have a particular influence on girls’ choice of majors in STEM related fields, which is important in contexts where course taking plays a gateway role for university coursework and in contexts like Malaysia where STEM matriculation is predicated on following a technical track in secondary school. Rayman and Brett (1995) found that women in the U.S. who received support from both teachers and advisors are more likely to persist in science after graduation than those who receive support from a single source. For Malaysian PEs, multiple sources of support seemed to reinforce a robust sense of professional identity.

Gendered identity within professional spaces

As Malaysian engineers described their experiences, a picture of two distinct spaces for working identities were circumscribed: the office vs. the worksite (or “on-site”). Respondents described these two spaces as distinct, with one (office) being welcoming and a “fit” for women engineers and the other (worksite) being challenging, difficult, and at odds with the notion of women professional engineers. The worksite could include spaces such as offshore oil rigs, a construction site, or a factory floor. These sites were seen as in conflict with the identity of women engineers, so much so that they would require “special accommodations” when women chose to enter these spaces. On the contrary, office engineering work was seen as better a better “fit” for women.

Respondent 3: I have friends, she’s a civil engineer so yeah people around her talk, “Why are you onsite, you are a woman that is men’s work.”

Interviewer: Yeah. They tell her that.

Respondent 3: Yes, but she say, “We’re engineer also.”

This distinction between the office and the worksite defines two very different spaces in which women engineers in Malaysia work. Rather than delineating the field or occupation in terms of gendered identity (which work in the US shows delineates gendered choices (Cech, 2013)), women describe gender-segregation in the types of work sites themselves within the field of engineering. Interestingly, though, this does not seem to relate to their choice of
working in an office or at a worksite. What this does, in a sense, is create an “acceptable” space within engineering for women and reinforces the idea that in terms of identity, “women” and “engineering” can go together.

**Professional identity fits with specific notions of femininity/masculinity**

Finally, we also see that respondents’ gendered identities fit with some (not all) gendered notions of the field of engineering. That is to say, their personal gender identity and professional identities are not in conflict. For example, one cluster of categories describes a sense of balance and equal treatment in engineering workspaces for men and women. Another cluster described the “normalcy” of women in the profession of engineering. Again, there was still an interesting juxtaposition with gender essentialist notions in engineering work – e.g., women in engineering not being able to perform certain tasks. This is also reflected in the distinct office and worksite identities described above. In addition, though, we see that women’s gendered identities fit with concepts of feminine and masculine identity for Malaysian PEs. Respondents reported a passion for engineering and, as noted in a few specific sub-themes, a sense that women were a better fit for engineering.

**Respondent 4:** “Actually, I like to accept challenge also. When I’ve been in working with construction always site work. When they assign me site work, okay no problem. I think that I’m also having fun of it dealing with the subcon, dealing with the client and so with the congress especially because in construction everyday you really face problems, everyday different problems that how you need that, they need an immediate solution. You need to check if you can decide if not you check with your supervisors or your managers, that’s it. Actually, I also tried some work more in office work because I said, why that I've been here in this construction site work especially site inspection but I tried also some of the office work and I see it’s boring. I said, okay I can do this because I’m also trying if I can do the work. I can do this but it seems that I’m not really for this line of work. I prefer more challenge. I cannot just sit down for eight hours or 10 hours in the office then go home maybe it’s not my line.”

This sense that women’s professional engineering identities and personal identities correlate may reflect labor market history in Malaysia. One account finds that the symbolic association of the electronics industry with femininity in the Malaysia society originated with the mass recruitment of a largely female, largely rural, labor force coinciding with the opening of the Malaysian economy to the global market in the 1970s (Mellström, 2009). This influx opened up a representational space for women as reflected by one of the students interviewed in (Mellström, 2009) whose mothers or female relatives had worked in the electronics industry.

**Discussion**

**Malaysian PE identity and implications for Malaysia**

Professional engineering identity for respondents in this study was robust, and included both notions of gender as part of the professional identity as well as expectations of resilience. Women described an identity that recognized and also relished obstacles to engineering work despite their gender identities. They described identities that fit with engineering work as a field as a whole, but they also articulated identity conflicts in specific engineering workspaces (e.g., offices versus worksite). Their identities drew on and were reinforced by multiple sources of support, including educational experiences as well as family, peers, and mentors. This resilience on the part of Malaysian female engineers could also reflect early emergence of significant engineering/technical field – the emergence of the IT economy, and, with it, the recruitment of a women-dominated labour force, in contrast to non-technical fields (Mellström, 2009). Where researchers have described engineering workspace identity in North American contexts as a hyper-masculine workspace espousing “frontier masculinity” (Baharuddin, 2001), the Malaysian PE identity described by women engineers is or can be feminine. This may reflect
occupational gender segregation and perceptions/expectations of women’s high performance Mellström (2009). Or, as noted from other prior work, it could be because gender as a dimension of identity is not as salient as, for example, race. Nonetheless, race/ethnicity was not discussed by our respondents in the context of engineering identity, so we do not see evidence in support of Lagesen (2005). Either way, we do not see evidence of the complete separation of “technical/social dualism” (Faulkner, 2007).

Implications for US and elsewhere

In addition to the existing comparisons and contrasts we draw in situating each of our themes, we also describe overall implications for other contexts. We see a stark contrast in the level to which Malaysian women PEs have to perform identity negotiation in their professional space. This lack of conflict in personal and workplace identities stands in contrast to what (Faulkner, 2009) describes as “doing gender”, or balancing gender authenticity and inauthenticity to navigate workplace identities that do not fit with gender identities. While the pervasive gender norms that Faulkner describes can be related to the initial requirement for women to prove themselves as “real engineers”, the identity described by our respondents seems to recognize and embrace this and describe it as a welcome, initial, transitory challenge. Instead of “gender-troubled” identities (Faulkner, 2007, 2009), we see an identity that is robust, stable, and incorporates femininity, and one that does not seem to distinguish between professional and personal identities (Hatmaker, 2013).

Future work may further investigate the theme of “leadership”, which is emergent in the Malaysia PE sample. Prior work on engineering leadership identity in engineering practice points to a hybrid model of leadership identity specific to the field of engineering (Rottmann, Sacks, & Reeve, 2015). In addition, we will move on to case study analysis to further investigate the similarities and differences in engineering identity between women undergraduates, faculty, and practicing engineers, and across cases (Malaysia, Tunisia, and Jordan).

References


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Improving course retention rates in engineering education in refugee settings: Lessons from two case studies

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Abstract:
In the Spring semester of 2018, the authors facilitated an introductory engineering course in Kakuma and Azraq refugee camps. The course was designed within the constructs of an active, blended, collaborative, and democratic framework. Although the course faced many of the challenges that have been found to negatively impact student retention in the literature of higher education in displaced settings, we still achieved a retention rate of 100% in Kakuma and 93% in Azraq. The aim of this paper is to study this paradox and contribute to the literature on student retention within displaced settings by sharing findings from an empirical study of this engineering class. Our research suggests that in spite of the difficulties that arose over the course of the engineering class and their potential to disengage students, dynamic responses that fall under the conceptual umbrellas of relational and institutional retention practices such as peer support potentially mitigated these challenges and improved the likelihood of student retention.

Introduction
Engineering education in displaced settings like refugee camps is both scarcely practiced and under-researched, yet, there is strong interest from university-level learners for engineering. Previous studies describing the challenges of facilitating higher education courses in refugee contexts show that one of the most prevalent challenges that facilitators face is student attrition (Gladwell et al., 2016). Multiple reasons are provided in the literature, the most prominent of them being students’ health challenges, prior traumatic encounters experienced by the students, unreliable power supply, and low availability of resources for class activities (Burde, Kapit, Wahl, Guven, & Skarpeteig, 2017; Zeus, 2011).

In the Spring semester of 2018, the authors designed and facilitated an introduction to engineering course within an active, blended, collaborative, and democratic framework. The course, the second implementation of its kind, built on findings from the first course hosted in Azraq refugee camp, and was simultaneously hosted in Azraq and Kakuma refugee camps in Jordan and Kenya, respectively, in partnership with InZone, a University of Geneva center for higher education for refugees. Although the Spring 2018 course experienced the challenges described in the literature, including harsh and unpredictable weather conditions
as well as episodes of controversial conflicts within students’ group discussions, we were able to achieve student course completion rates of 93% in Azraq and 100% in Kakuma.

The need for student retention in engineering education has been described as vital, especially because engineering skills are in high demand for sustainable socioeconomic development (National Academy of Engineering, 2004). The need is just as dire in fragile settings as it is in stable settings where higher education has come to be seen as a tool for long-term development (Wright & Plasterer, 2010). The aim of this paper is to contribute to the literature on student retention in higher education courses within displaced settings by sharing our findings from an empirical study of an engineering class. The paper is divided into separate sections, beginning with a review of the literature of student retention in higher education and the approach that researchers and instructors have taken in the past to sustain student engagement and increase retention in engineering courses. Our focus, however, is not just investigating student retention in university engineering, but in refugee settings in particular. Thus, the research questions guiding the paper are as follows:

1. **What challenges do students see emerging in an engineering course facilitated in a refugee camp that have been shown to negatively impact student engagement or increase the likelihood of student attrition?**

2. **What supports do facilitators subsequently use to respond to these challenges, and what supports do students and facilitators describe as mitigating challenges and improving the likelihood of student retention?**

To answer these research questions, we performed an in-depth qualitative analysis of the multiple types of data collected from the two locations where the course was hosted (Azraq and Kakuma). We treated our settings as cases and employed a case study methodology in this paper. To identify the challenges that participants of this study faced in the course as well as the solutions that were then attempted, we used a chronological approach in our analysis of conversation data from the two camps. The data included conversations from different online fora set up between the Purdue instructional team (henceforth described as online tutors), local facilitators (henceforth described as on-site tutors), and the respective students from both settings, pictures sent by the students, and the online facilitators’ personal reflection journals. A chronological analysis was an effective way of answering our research questions in this study; it presented the emergence of the challenges that students, facilitators, and partners faced as the course progressed, conflicts that emerged during team engagements, and the solutions that were implemented to sustain student engagement and overall student retention. We used NVIVO software to code these data as well as identify emergent themes.

**Context of the Study**

The United Nations High Commissioner for Refugees (UNHCR) estimates that at the end of 2017, persecution, conflict, and general violence had forcibly displaced about 68.5 million individuals around the world, with 25.4 million of them being refugees and half of the refugee population being children below 18 years old (2017a). The population of refugees in Jordan is 653,000, with the Azraq camp hosting over 30,000 of them (UNHCR, 2018). On the other hand, Kenya hosts close to 470,000 refugees, with approximately 40% of their population residing in Kakuma camp (UNHCR, 2017b). The Kakuma refugee camp population consists of people from Somalia, Uganda, Sudan, South Sudan, Burundi, Democratic Republic of Congo, Eritrea, and other countries in the region, while the Azraq camp hosts Syrian refugees. These refugees have first, second, and, in some cases, third languages other than English. Refugees in Azraq predominantly speak Arabic. In Kakuma, refugees might speak Kiswahili, French, and in some cases, a third language in addition to English (above and beyond mother tongues).
Engineering course framework

Our research group designed an engineering course for higher education learners of the Azraq and Kakuma refugee camps. The goal of the course was to equip learners with engineering skills, foster critical thinking, and enable students to solve problems faced within their local communities. The team sought to put research into practice by designing the course within the constructs of an inclusive learning environment. Constrained by resources, the team designed the course for a maximum capacity of 20 students in each camp. In total, over 50 interested applicants attended a 3-day pre-course workshop and took the entrance exams in both camps. 20 students were selected for the course in Kakuma and 15 in Azraq. The course was designed within an active, blended, collaborative, and democratic framework (ABCD for short). The explanations of each aspect of the framework and supporting literature about the effectiveness of each follow in brief descriptions, and more detail about this framework is available in other work by this group (e.g., Freitas, Beyer, Yagoub, & DeBoer, 2018).

Active. Active learning has been identified as one of the most effective ways to focus learning on the learner instead of the instructor (Chi, 2009; Smith, Sheppard, Johnson, & Johnson, 2005), and its role in fostering student retention has been discussed in previous studies (Orjuela-Laverde, Yargeau, & Smilovic, 2017). In our course, this involved engaging students in hands-on activities contextually aligned with local needs in the respective refugee camps, all of which culminated in a capstone project.

Blended. The blended nature of the course refers to the provision of a physical learning hub in Azraq and Kakuma for class sessions, as well as an online learning platform through which students accessed the course modules, videos, and slides on tablets in the hub, and submitted their assignments. Local facilitators were also available to provide support to the students. In Azraq, the local facilitators consisted of students who were graduates from the first version of the course. In Kakuma, the local facilitators were graduates of other higher education programs in the camp. Students were virtually supported by the online instructors in real time via an online messaging forum throughout the course.

Collaborative. The role of peer collaboration has been investigated in literature, in particular in science, technology, engineering, and mathematics (STEM) settings, and found to have a strong positive correlation with student engagement and retention (Johnson, Johnson, & Smith, 1998; Smith et al., 2005). In this course, students were required to autonomously form teams in which they would work up until the presentation of their group capstone projects, and in some cases, even beyond.

Democratic. The concept of a democratic classroom was based on Freirean critical pedagogy (Freire, 1970) and aligned with previous studies of courses facilitated in refugee contexts within this framework (Magee & Pherali, 2017). In our course, democratization involved amplifying the decision-making roles of students throughout the course. This manifested in the form of democratically setting the course rules and regulations with the students as well as negotiations of penalties for absenteeism and late assignment submissions. More broadly, critical pedagogy engaged students in identifying problems around them and taking the lead in designing solutions for their own communities.

The course was facilitated in three phases: a 3-day workshop (to provide students with a model of what to expect from participation), a 12-week blended learning period (where students identified a problem in their local community and devised a solution to it), and a capstone project presentation (which included presenting prototypes of their solutions, the design process, and the role of all team members). Students were encouraged to continue to work on their capstone projects after the course was completed to develop them into full-fledged solutions that would be of benefit to their local communities. Although less structured than the actual course, these independent projects afforded passionate students an opportunity to continue to engage in learning and collaborative engagements long after the course officially ended.
Literature Review and Conceptual Framework

Engineering education in refugee contexts is a new and little-explored field. To ground our work, we build on literature using the intersectionality of two hitherto separate fields – student attrition/retention in engineering education and student attrition/retention in refugee education.

Tinto’s model of persistence (1975) is frequently cited in the discussion surrounding student retention in higher education. In short, the model suggests that students persist when they successfully integrate into their respective institutions on academic and social dimensions. Since its postulation, the integration model has undergone extensive expansion and further study. For instance, a relevant study identified three broad practices that help “non-traditional” students (those who are underrepresented in higher education) to improve their retention in higher education (Kurantowicz & Nizinka, 2013). These practices were classified as biographical, institutional, and relational, although synonymous categorizations like individual, institutional, and social/external support, respectively, have been used in other studies (Jensen, 2011).

Biographical/individual retention practices refer to personal educational experiences, self-esteem, and what has been described in related literature as “grit” (Chen et al., 2015). Institutional retention practices refer to the social and cultural capital that an institution or organization factors in as it consciously makes decisions to improve the likelihood that students will have a sense of belonging and inclusion in the institution. Relational retention practices are described as social support systems that students turn to as a means to sustain their engagements and perseverance (Kuh, Kinzie, Buckley, Bridges, & Hayek, 2006).

Relational retention practices are characterized by reciprocity – the case where students do not just receive support from other students but also provide support as well in a mutual growth process (Kuh et al., 2006). Each of these three practices determines students’ retention in higher education programs.

While personal attributes have been shown to strongly relate to student retention and attrition in higher education courses, we agree with research showing that they are only a piece of the puzzle. The framing of our research question focuses on the other two practices – institutional and relational which could be interpreted from Kuh and colleagues’ review as organizational and cultural/sociological perspectives (2006). These two perspectives are the focus of this paper. The review suggests that organizational or institutional retention practices include teaching and learning approaches, educational philosophy, active and collaborative learning pedagogical approaches, providing timely and useful feedback to students, as well as appropriate instructional technology (p. 13). Relational or cultural retention practices include “effective student-faculty contact, development of practical competence, and peer group interactions” (p. 14). The review also asserts that, of these, peer group interactions were identified as some of the most “powerful indicators of student success” during and after college (p. 87). The review, however, casts a wide net in defining what constitutes student retention. The scope of our one-semester course causes us to limit this definition to one that defines students persisting to completion of their educational goals as a key gauge of student retention (Voigt & Hundrieser, 2008). Thus, in this paper, we define student retention by the percentage of students who persist through the three phases of the course to the completion of the course goals and receipt of course credit.

Methodology

As a case study, the data for this research were collected from various sources: conversation data on the online fora, online facilitators’ personal journal reflections, and pictorial images from the students and on-site facilitators. Student-facilitator conversations were the primary source of data. From this data source, we applied the chronological analysis method (Mills, Durepos, & Wiebe, 2018) to identify the various problems students faced in the course and the subsequent solutions proposed to sustain student engagement and retention.
Chronological analysis in case study research differs slightly from content analysis in terms of its appropriateness for sequentially ordering events in the successive manner in which they occurred (Mills et al., 2018, p. 145).

In this analysis, we recognize the cultural and methodological biases that we bring in as researchers. Rather than disregard the fact that our positions as facilitators and researchers from a large predominantly-white mid-western American university could serve as an existing power differential between the “researcher” and the “researched” and between “teacher” and “student”, we anticipated and recognized them early. With this anticipation came valid questions about how the data we collected would be interpreted. In our case, these considerations were intertwined in our multifaceted roles as course designers, facilitators, and researchers. Thus, we employed an inductive analytical method that facilitated the emergence of findings from the content of the participants’ own words, which would minimize our interpretations of what they were saying. To triangulate the results, we referred to other sources of the data to confirm or confound the findings (Yin, 2009). The analysis of the online conversations followed an abductive approach (Timmermans & Tavory, 2012). The first author worked with a co-author by using a modified version of the standard iterative process (MacQueen, McLellan, Kay, & Milstein, 1998) to develop a codebook for the thematic analysis of the conversation and survey data for this study. While the first analyst performed three iterative immersions in the textual and visual documents, generating his codes in vivo (inductively), the second data analyst developed codes from a review of the literature (deductively) relevant to the research. In the first pass, the first analyst coded the texts of the online conversation that were directly related to the first and second research questions. These codes emerged chronologically in vivo. In the second pass, the analyst compiled similar codes into parent codes and thus developed the categories for defining them. In the third pass, the analyst described the inclusion and exclusion criteria for the parent categories. The second data analyst generated codes from a review of the literature on student retention and attrition in higher education courses in refugee settings and in engineering education. Similar codes were categorized into parent codes and inclusion and exclusion criteria also generated for each code. The codes developed by both analysts were then compared to investigate fit and reliability. Given the scope of our work, we do not present the codebook but draw excerpts from the codes in the presentation of the results.

While we do not claim to have exhaustively addressed all the possible limitations to our analysis, we would argue that the purpose of the revised abductive approach coupled with the chronological analysis was to allow the findings from the data to emerge in vivo (Ellingson, 2009). The final codebook consisted of 4 columns: the name of the code, fully operationalized descriptions based on an appropriate review of literature, inclusion and exclusion criteria that described in finer details how the codes were identified and distinguished from other codes, and a final section that provided samples of the codes pulled from the data. Results of this analysis process follow.

Results: Summary and Detailed Presentation of Key Findings

An analysis of the online conversations confirmed the emergence of some of the problems that have consistently been identified in the literature of higher education in refugee settings (Borde et al., 2017; Chelpi-Den Hamer, 2011; Student, Kendall, & Day, 2017; Zeus, 2011), some causes of student attrition from higher education in other settings (Adusei-Asante & Doh, 2016; Beer & Lawson, 2017; J. L. Johnson, 2007; Maher & Macallister, 2013), as well as causes of student attrition from undergraduate engineering education in general (Honken & Ralston, 2013; Imran, Kalil, & Hayati, 2013; Knight, Carlson, & Sullivan, 2007). Our findings are organized by the research questions, discussed in the following subsections, and summarized in the table.

RQ1: Challenges

The following challenges are presented in the order in which they emerged from the analysis
as they were identified by the students or the on-site facilitators of the course: language, electrical power, weather, online learning platform, student-student conflict, internet access, IT fluency, illnesses, accidents, computer viruses, download problems, operating systems, time-zones, ventilation, absent facilitators, inaccurate provision of materials, and inaccurate problem statements. To better categorize the data, problems related to power supply, internet access, the online learning platform, IT fluency, computer viruses, downloads, time-zones, and operating systems, were further grouped under “technical difficulties”. Although each of these were described as notable challenges that impacted student engagement in the course, we limit our more detailed presentation of findings from the data analysis to the most frequently mentioned challenges.

**RQ2: Mediating Support Structures**

The chronological analysis method afforded an opportunity to match each challenge that surfaced with the associated response, strategy, suggestion, recommendation, or proposed solution that followed. A more detailed explanation of such a process is described in the detailed presentation of the key findings. It explains the appropriate solutions that were either suggested by students or implemented by the online tutors and on-site facilitators to sustain student engagement and improve the chances of student retention. The analysis revealed 26 different codes which were further classified into themes. Of these, the most significant ones that emerged from the analysis were peer support (student-student interactions, engaging students as co-problem-solvers, and facilitating cross-camp connections between Azraq and Kakuma camp residents), ethics of care (Pantazidou & Nair, 1999) from online and on-site

<table>
<thead>
<tr>
<th>Challenges</th>
<th>Solutions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language</td>
<td>Translating course content to Arabic and French; providing access prior to the start of class, encouraging students to converse in languages in which they felt most comfortable; translating conversations on the online forum</td>
</tr>
<tr>
<td>Technical difficulties</td>
<td></td>
</tr>
<tr>
<td>Internet access</td>
<td>Troubleshooting connections</td>
</tr>
<tr>
<td>Electric power</td>
<td>Engaging students as co-problem-solvers</td>
</tr>
<tr>
<td>Online learning platform</td>
<td>Offline downloads of course content</td>
</tr>
<tr>
<td>IT fluency</td>
<td>Student-student interactions, troubleshooting</td>
</tr>
<tr>
<td>Computer viruses</td>
<td>Conferring with onsite facilitators, troubleshooting</td>
</tr>
<tr>
<td>Operating systems</td>
<td>Student-student interactions, troubleshooting</td>
</tr>
<tr>
<td>Download problems</td>
<td>Student-student interactions, troubleshooting</td>
</tr>
<tr>
<td>Time-zones</td>
<td>Conferring with onsite facilitators</td>
</tr>
<tr>
<td>Weather</td>
<td>Weathering the storm: modeling to students that their health, safety, and welfare come first (ethics of care); throwing the challenge back to the students to think through rather than providing instant solutions</td>
</tr>
<tr>
<td>Illnesses</td>
<td>Seeking out the unusually offline and the conveniently silent</td>
</tr>
<tr>
<td>Accidents</td>
<td>Seeking out the unusually offline and the conveniently silent</td>
</tr>
</tbody>
</table>
facilitators (caring for students’ health statuses, resolving valid cases of absenteeism, seeking out the ‘unusually-offline’, seeking out the ‘conveniently-silent’), conferring with on-site facilitators for advice on context-specific decisions, soliciting on-site facilitators’ suggestions on course improvement, and facilitating post-course engagements (continuing independent projects, certificates and transcripts). One of the most notable challenges we faced in the course was language, as Table 1 shows. While overcoming the language challenge required a complex iterative process, we assessed it to be just one of the multiple challenges faced in the course. In order to address multiple challenges for the scope of this paper, we limit our discussion to the following two themes which, together, comprise four of the most significant challenges identified (in terms of the frequency with which they were mentioned by the course participants as represented in Table 1) with brief descriptions and excerpts from the research data, and the proffered solutions to each of these problems (RQ2) based on the findings of the chronological analysis.

Weathering the storm: Overcoming harsh, unpredictable weather conditions, technical difficulties, and interrupted power supply

Weather conditions were harsh and largely unpredictable in Kakuma. The InZone learning hub where students attended classes was located beyond a riverbed which remained dry for many parts of the year but posed a challenge anytime it rained. Although this desert region experienced few cases of rainfall each year, outdoor activities stopped when it did rain, flooding streets and paths so much so that transportation and access were practically impossible. The following excerpt briefly describes the conversation on one such occasion:

“Hello team, Kakuma has changed. At the moment, it is heavily raining. Students won’t manage to reach to the center. Yeah, even our colleague who should open the hub was blocked in the other side of the river due to floods. No way to make it today.” (On-site facilitator, Kakuma, Week 4)

The unpredictable weather conditions had a strong impact on the course. Not only did heavy rainfall flood streets, riverbeds, and affect transportation, students also sent pictures that showed how strong winds tore down shelters in settlements around the Kakuma camp. In less severe weather conditions, cloudy days also affected classes. The fact that the learning hubs relied on energy from solar panels posed a big challenge on cloudy/rainy days. This problem led to the instability of power supply and in some cases, none for classes. The chronological analysis reveals what actions we took when this problem surfaced. First, we modeled to students that their health safety and welfare come first. During extreme weather conditions, the first thing the facilitators did was to instruct students to stay safe.

“We understand the conditions, [student1]. Few of you are at the center and it is completely hard to make it. Heavily raining. Plz keep safe” (On-site facilitator, Kakuma, Week 4)

“It’s raining in Kalobeyei? Hope you didn’t go out in it…?” (Online facilitator, Kakuma, Week 4)

In the less severe conditions when students were already in the class, the chronological data analysis reveals that we engaged students as co-problem-solvers of the problem of power supply. An excerpt that exemplifies this process is presented below:

“Hello [student 1], I have received your work. I am sorry about the power situation. It must have been a challenge. And [student 2], I got your message too. Power outage is a common problem in Africa, and I wondered if you might learn something from it. Allow me to ask, based on what you have learned so far, what do you do when you have a power outage problem like that in the future?... So how would you, as students, be able to still hold classes in the future, even if the electric power is cut off? No answer is wrong. Please let us know what you think.” (Online facilitator, Kakuma, Week 3)

Engaging the students as co-problem-solvers led to some valuable discussions that ended up being course capstone projects and post-course independent projects for some of the students.
Resolving negative effects of illnesses and accidents on student retention: Seeking out the unusually-offline, seeking out the conveniently-silent

In Azraq and Kakuma, there were more than 11 different cases of illnesses recorded among the students and the on-site facilitators during the course. Some were mild illnesses that did not warrant any special attention, while others were serious enough to lead to full admittance at the residential health centers in both camps. In Kakuma, two of our students sustained injuries as they traversed long and treacherous paths that led to the learning hub. Conditions in refugee camps are less than ideal, and literature supports the assertion that residents suffer from physical illnesses in addition to traumatic experiences that affect their mental health (Doran-Myers & Gfroerer, 2009). Injuries sustained during wars or in the flight from their home countries are also strong causes of students’ attrition from courses. Yet, cases of illness and accidents are not exclusive to refugee settings, and they have been identified as potential causes of students’ disengagement from courses even in stable settings (Christo & Oyinlade, 2015; Kuh et al., 2006).

Two broad sub-themes that described our varied attempts to sustain student engagement in our course in the face of illnesses and accidents were: diligently seeking out the “unusually-offline” and diligently seeking out the “conveniently-silent”. We described the “unusually-offline” as the students who were habitually active in the course and in the online conversations but suddenly became quiet, and the “conveniently-silent” referred to the students who preferred not to talk in the online group discussions. Three common responses were identified in our data analysis in this study as chronologically following identification of illnesses and accidents in our course:

1) Setting up a system that made students’ absences visible albeit with a cautious understanding that students’ privacies had to be protected. In our case, students kept attendance and were encouraged to notify the group if they would be absent.

2) We intentionally reached out to these students to let them know their contributions were valued and they were missed when offline. Our analysis of the conversation forum suggests that the students who were sick or suffered accidents were anxious to return to class because of the care and consistent communication that the facilitators and their peers showed to them while they were away.

3) Tasking friends or team members with bringing the affected students up to speed. This was very helpful in our course, as it ended up becoming a model for students to work offline.

Conclusion

Although the analysis is still ongoing, in this work-in-progress paper, we presented our current findings from analyzing the data collected from an engineering course facilitated in two refugee camps in Azraq, Jordan and Kakuma, Kenya. The results of the chronological analysis clearly show that enabling or amplifying peer-peer and peer-local facilitator connections was the most frequently sought-out solution to the issues that arose in the course. This finding is in consonance with the sociological perspectives of Tinto’s persistence model (Kuh et al., 2006) and the assertion that relational retention practices are strong determinants of student retention. The analysis also revealed that the instructional team’s organizational/institutional practices including the philosophy of engaging students as co-problem-solvers and modeling ethics of care in times of illnesses, accidents, and severe weather conditions may have had a positive influence on sustaining student engagement and perseverance. Using a chronological approach in our analysis, we identified challenges to the facilitation of the course in these two settings as they emerged, and we identified the solutions that were suggested as mediating strategies for each challenge. Our analysis revealed multiple factors that could be related to the 100% course retention we achieved in Kakuma and the 93% course retention in Azraq. In this paper, we discussed only four of these findings categorized in two subheadings – unpredictable weather conditions, technical difficulties, power instability, and the benefits of prioritizing care first before engaging
students as co-problem solvers of these challenges; and cases of illnesses and accidents and the importance of intentionally seeking out the ‘unusually-offline’ and the ‘conveniently-silent’. Our next steps are to investigate the variations in the experiences between these two cases and to conduct interviews with the students and onsite facilitators of these courses to confirm or confound the findings of this analysis. We hope our findings from this study inform engineering education instructors that high student retention is possible, even in displaced settings.

References


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An Air Quality Inquiry: A Curricular Approach to Preparing Student Mentors of Air Quality Research Projects in Rural Schools

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Abstract: The present investigation delves into the impact of a yearlong engineering outreach course on the development of technical and professional skills as well as the engineering identity of university mentors. Using a sociocultural development framework, the preparation of student mentors is investigated with respect to course structure, the guidance of mentors and the development of their skills and identity. Data were collected from student mentors via surveys, focus groups, classroom observations and interviews. Results indicated satisfaction with the course and the guided instruction. Survey results revealed strong gains in technical skills and mixed results for professional skills development. Shifts in student identity were observed. Results are integrated into the existing literature on pre-college and K-12 engineering. Recommendations for practice are provided.

Context

Important outcomes of an engineering education are the skills, knowledge and motivation to address technical issues in society and to interact with a wide range of audiences across a variety of contexts to assist with such tasks as the development of younger engineering professionals and students (Passow & Passow, 2017). Yet, engineering students are exposed to fewer settings which allow for the simultaneous development of these types of skills and attitudes as most of the engineering curriculum is heavily focused on mastering narrow technical engineering concepts. The few opportunities for broad development in these areas for engineering students tend to be housed outside the curriculum in student clubs or conferences with design courses often the only common curricular component to focus in these areas. The present study investigates the impact on university students of an alternative curricular approach, a yearlong university course focused on K-12, pre-collegiate outreach and learning to mentor air quality inquiry based research projects in rural secondary schools in the U.S. Mountain West (Knight et al. 2016).

Literature Review

This paper is focused in a K-12 setting with a particular focus on secondary schools targeting US grades 9-12. Across the world, countries have recognized the importance of pre-collegiate education in Science, Technology, Engineering and Mathematics, collectively
known as STEM education (Hynes et al. 2017). In the United States (US), calls have been made by the government to better integrate engineering into pre-college or K-12 curricula. For example, the US National Research Council (NRC) has recognized the importance of engineering as a tool for integration of other high school subjects such as science, technology and math through engineering subjects as design (NRC, 2009). This has led to the creation in the US of the Next Generation Science Standards for K-12 science education which includes engineering as a part of the curriculum and has been influential in the science curriculum of many states (NGSS, 2013; Ryan, Gale, and Usselman, 2017)).

Hynes et al. (2017) conducted a systematic review of K-12 engineering education research and found that most studies focused on secondary students as participants in a high school classroom context with affective outcomes towards engineering as the primary dependent variable. A smaller number of studies investigated the experiences of the adults in K-12 settings with the large majority of those studies focused on practicing K-12 teachers. The present study investigates the development of university students as research mentors in K-12 settings and targets a less frequently studied population in K-12 engineering education settings.

While the bulk of engineering education studies address K-12 student and teacher development in K-12 settings, some studies have found a positive impact on university students who work in these settings. Studies have found that experience in a K-12 setting has developed university students’ science teaching efficacy (Thompson, Watson, & Lyons, 2010), STEM content knowledge and communication skills (Zarske et al. 2008), and, in a study focused on the development of classroom mentors, organization skills and the ability to reflect on lesson plan delivery (Nelson, et al. 2017). These outcomes dovetail with a recently published list of competencies important for engineering practice including skills at applying technical foundations, communicating effectively, and managing one’s own performance (Passow & Passow, 2017).

Engineering education outreach interventions usually feature an engineering design project as an integrating tool for math and science concepts (Moore et al. 2014). However, one framework for a quality K-12 engineering education details other important areas of the curriculum in addition to design including topics such as engineering thinking, ethics and the use of engineering tools (Moore et al. 2014). This topic of engineering tools is the focus of the present study in the form of an environmental monitoring tool. This tool was developed from the perspective of citizen science to support inquiry based learning practices in the classroom. For more insight into how citizen science is used for inquiry based practices in K-12 settings, refer to this overview by Gray, Nicosia, and Jordan (2012).

This paper also is focused on a curricular learning environment for training university student mentors as opposed to a co-curricular or club setting for training students for outreach. Courses to train university students for outreach are described in the pre-college engineering literature. One model is a course in the universities’ school of education where engineering students learn issues related to teaching science and engineering in a university setting (Thompson, Watson, & Lyons, 2010). Another model describes the development of a service learning course offered in engineering for teaching outreach skills to engineering students (Jeffers et al. 2004) Here, university students are partnered with K-12 students and teachers to develop hands-on math and science activities while learning how to offer an introduction to engineering as a career. The paragraphs below detail the specifics of the outreach learning environment including the university course and K-12 setting.

Program Overview

This two-semester course has undergraduate and graduate sections and offers one hour of academic credit in the fall and two hours of credit in the spring. The course provides technical elective credit for a required part of the engineering curriculum and has both strong technical objectives around air quality science and engineering along with emphasis on “soft” or professional skills in the form of communication and mentoring skills.
The course is housed in the mechanical engineering department at a large US public university in the mountain west, but recruits university students from across all engineering majors. The first semester of the course is focused on the preparation of the university students as mentors for work in K-12 settings with exposure to an online five-module, inquiry-based air quality science and engineering curriculum known as Air Quality Inquiry (AQ-IQ). The inquiry-based component instructs mentors to ask questions about air quality in their local environment and use the air quality monitoring equipment (known as Pods) to answer the questions. (Knight et al. 2016.) Other modules focus on the analysis of collected data and the communication of results to community members and other stakeholders.

Mentors build their technical knowledge by selecting and working through an air quality monitoring project similar to the ones they will be mentoring the following semester. During the process of selecting and completing the project, mentors work through the hands-on components of each module, testing out the monitor by measuring the impact of emissions from a tailpipe in the school parking lot, brainstorming their own inquiry based questions and using the monitor to answer them and presenting their results in class for a grade. Throughout the process, mentor and communications training was embedded in the process by stopping the activities and reflecting and practicing ways to teach them to high school students. Also, university mentors were coached on having discussion with high school students about selecting a college and major.

University mentors began to transfer this training in a supervised trip at midterm of the fall semester to a rural K-12 school where they will be mentoring students the following semester; in this initial visit, they introduce the project in their K-12 classrooms and build relationships with the K-12 students and teachers they will be working with. Mentors run an ice breaking activity outdoors and introduce the monitoring equipment. Then, they walk high school students through their own inquiry-based project completed in a university classroom. During the first supervised visit, mentors were coached and debriefed in the field on the same communications and research mentoring skills related to completing a project and investigating universities.

Figure 1: University mentors running an ice-breaking activity with rural high school students.

After the first semester, the focus shifts from structured preparation at the university to monthly travel to rural high school K-12 classrooms. All rural K-12 partner schools are located outside the metropolitan area of the city where the university is located, with
distances ranging from two to five hours driving time. Several of the schools are in rugged mountain terrain and logistically challenging for mentors, especially during the winter. These are often overnight or multi-day journeys. Others schools are a daytrip from the school into more accessible rural areas to satisfy the needs of all mentors who are taking multiple classes in addition to the target class.

Prior to the second semester at the end of winter break, mentors spend a week in the K-12 classroom at their schools helping K-12 student teams and teachers develop a three-month air quality monitoring project. Mentors assist with brainstorming high school student research questions about air quality problems in their local community and equip high school students and teachers to collect, analyse and present their data in their local community. K-12 student teams employ a portable, low-cost air quality monitor known as “Pods” which allow them to measure air quality indicators such as carbon dioxide, humidity, volatile organic compounds, and temperature. Student teams have investigated a wide variety of air quality research questions ranging from agricultural emissions at local ranches, air quality around fossil fuel extraction sites across the continuum to differences in air quality in different parts of their homes, schools and local businesses. Mentors also make time to discuss academic pathways to college and discuss various majors including the process of an engineering major.

The project culminates in the local rural community with a science and engineering symposium where K-12 student teams present their projects in a poster session to mentors, university personnel and invited community members. Mentors provide input and coaching on posters which are presented and judged by university personnel and community members. Winning teams and other interested students are invited to the partner’s university-wide engineering design expo featuring a wide-range of Capstone design projects from university seniors. K-12 students who visit the university are hosted by their mentors and given a personal tour of the design expo as well as university laboratory space and other university facilities. Symposiums wrap up with a month to go in the semester. At this time, mentors transition to a focus on documenting and reflecting on their projects through team audiovisual projects that often take the form of developing a short video that captures some facet of their experience or provides instructions for future students or mentors to improve understanding or performance on the projects. The course wraps with a presentation of these videos and a final assessment period.

**Research Questions**

This study explores the following research question: How does a course focused on learning to be a mentor for air quality inquiry based projects in a rural high school develop the skills, attitudes and identities of university engineering students? This study is important for engineering education because it investigates an avenue for the development of engineering students in both the technical areas of air quality science and engineering as well as the soft or professional skills of communication and mentoring which are helpful for the universities’ accreditation purposes (ABET, 2019) and for student transitions into industry settings.

The study also probes any changes to university student mentor identity as an engineer, an air quality expert, a communicator, and a mentor such as interest in air quality monitoring, a developed interest in teaching or mentoring, or working more frequently in K-12 contexts. This study also investigates a more novel approach to this type of skill development, a project based learning course taken for technical credit that counts toward graduation requirements and that is housed within the traditional engineering curriculum.

**Theoretical Context**

We apply a sociocultural activity framework of participatory appropriation, guided participation, and apprenticeship (Rogoff, 1995) to the classroom and field settings of the course to further understand learning and development in context (See Figure 1 below). This
framework was designed for the observation of development in educational settings. Previous frameworks for this type of observation have been limited by a focus either on the individual or the separate elements of the environment. This framework offers a more integrated perspective for the analysis of study data from multiple learning contexts with lenses related to community, interpersonal, and individual development that are mutually defined and interdependent.

Figure 1. Rogoff’s (1995) framework: Learning through participation on three planes of sociocultural activity. This figure identifies the structures of activities which supported learning opportunities: Apprenticeship with mentorship components, guided participation, and participatory appropriation.

At the community level, these inquiry based high school projects are structured as a course that emphasizes classroom and fieldwork components. This course can be viewed as an apprenticeship with mentorship component(s), where university mentors learn how to use air quality monitoring equipment, perform their own inquiry led research project, develop lesson plans for youth across different areas around the mountain west, and facilitate those lessons in the K-12 classrooms. These sites of community engagement functioning as apprenticeships, contain a community of individuals and a “specialization of roles oriented toward the accomplishment of [communal] goals” and which focus on “a system of interpersonal involvements and arrangements in which people engage in culturally organized activity” and in which newcomers take on increasingly sophisticated tasks and responsibilities by advancing their knowledge and skills via participation in that community (Rogoff, 1995, p. 143).

On the interpersonal plane, university and K-12 teachers scaffold mentors’ efforts in learning to mentor the development of a research question, designing an experiment to carry out, controlling and minimizing the effect of variables in the field, collecting data, data analysis, and dissemination of research findings. University mentors develop research projects that center around personally and scientifically relevant topics. In addition, classroom teachers often incorporate mentor projects into the science curriculum, and coordinate with mentors to further guide them along in their mentoring of K-12 student projects. Through guided participation there is a transformation of the individual university mentors as participants’ appropriate skills and increase knowledge of practices.

Rogoff (1995) defines the transformation of novices, on the individual plane, as participatory appropriation (p. 150), in which individuals participate in the apprenticeship with guided participation, and develop into a more knowledgeable and skilled person. In this transformation, the participant has appropriated the skills necessary to take on increasingly sophisticated tasks and responsibilities. In this process mentors engage in new ways of thinking about the world, increasing self, social, and global awareness (Ginwright & Cammarota, 2002). Thus, engaging with the class and community can lead to mutually beneficial outcomes for all partners.

In summary, as participating university students perform research mentoring, they are guided in their participation and appropriate skills and knowledge to participate in the community as a more knowledgeable peer, which affects identity and in future circumstances. As mentors facilitate educational experiences and guide high school students in their projects, they also practice and refine skills within engineering, and develop teaching and mentoring skills.
present investigation seeks to examine development of skills, identity, and attitudes throughout the yearlong outreach course.

**Methodology**

This study employs a sequential explanatory mixed-method design with survey questions employed to investigate the quantitative impact of the course on the development of student mentors followed by qualitative observations, focus groups, and interviews to provide for a richer exploration of student development (Creswell, 2013). Mixed methods were chosen to provide quantitative results which are important indicators of impact in a quantitative field such as engineering along with the richer qualitative data which is more strongly represented in the education side of engineering education. In Hynes’ et al. (2017) review of the pre-collegiate engineering education literature, mixed-methods studies were a less frequently employed design (19% of reviewed studies), and this study adds to these results. Participants in this study were self-selected as 32 students who enrolled in the course as a technical elective in the College of Engineering and Applied Science. All students except for one were engineering majors with one student from physics.

The investigation incorporates data collected across three years of the course from mentors who worked in eleven secondary schools in rural settings in a US state in the mountain west, including the current year for which partial data is provided at the time of this review. Data for the first two years were collected by course instructors with two classes of eight mentors, but for the current year the course doubled in size to 16 mentors and a partnership was developed between the university’s college of engineering and school of education. For year three of this investigation, school of education researchers have designed and conducted the research.

For year one and two of this investigation, pre- and post-surveys for the course were selected as a method for determining quantitative gains on targeted skills and attitudes. Technical skills were assessed via self-ratings of knowledge of air quality content and monitoring while professional skills were measured via self-ratings of communication and mentoring skills. Participants also made ratings on the post-test of the usefulness of the curriculum and whether they would recommend the course or have an interest in future K-12 work.

Survey respondents provided numerical, Likert-type ratings of their skills and content knowledge for the purpose of gauging technical and professional skill development of the engineering mentors across the year. Quantitative data were averaged pre to post assessment for each skill. Post-survey data from year 3 was not available at the time of publication. Although the current data set is too small for testing of statistical differences, percent differences were calculated.

Qualitative research methods drawn from ethnographic research strategies were employed across all three years of the investigation with data collected in the form of field and classroom observations, open-ended survey questions and annual focus groups (O’reilly, 2012). In the third (current) year of the study, a partnership with the school of education at the university was developed. These researchers added semi-structured interviews and more extensive ethnographic observations to the study (O’Reilly, 2012). Qualitative data were documented and coded using methods from Grounded Theory to provide an iterative and inductive data collection and analysis process (Charmaz & Mitchell, 2001). Rogoff’s (1995) framework was used as a lens for organizing the data.

**Findings and Conclusions**

This investigation explored the following research question: How does a course focused on learning to be a mentor for air quality inquiry based projects in a rural high school develop the skills, attitudes and identities of university engineering students? Results are presented through the lens of Rogoff’s (1995) model with results organized along the community plane.
which maps to mentor experiences of the impact of the course process on skill development, along with the interpersonal plane which maps to guidance provided to student mentors via a curriculum and teachers, and the individual plane which maps to the development of student technical and professional skills as well as shifts in students’ identity. Table 1 displays the quantitative results from the survey and student comments are woven in under each section heading.

**Community Plane**

On the community plane, university mentors provided feedback and reflections on the course process and how it was structured to allow for the development of their skills. One student mentor commented, “I like how the class was set up where we all could just talk to each other rather than just a professor lecturing at the front of the room. It’s a great opportunity to get some teaching experience. Getting to work with the Pods and use them was fun and a great introduction to the technology that’s out there. It helps strengthen communication skills and professional skills.” Another student commented on a strength of the course structure as, “having to go to the (K-12) classroom and have actual outside experience with the course. Also, we had the opportunity to learn along with the students as well. It was fun and engaging, and felt like I accomplished something rather than turning in homework every day.” Finally, one student mentor commented, “It was very useful to have the mentors conduct our own research projects, as we had to learn to troubleshoot the PODs before handing them off to the classrooms.” Across the first two years, survey results revealed that 100% of university student mentors would recommend the course to others.

These findings are in line with results from other studies targeting best practices for the structure of service learning courses for engineering education students. Components such as multiple stakeholders, active learning, teamwork as well as classroom and field settings found in these types of courses are all important for university mentor development (Jeffers et al. 2004).

**Interpersonal Plane**

On the interpersonal plane, student mentors also provided feedback on their experience of teaching a provided curriculum in the classroom, “The curriculum was strong. Lots of supplemental information that would be useful for teachers to use whenever they have time.” The majority of mentors (86%) reported on the survey that the on-line curriculum and modules were sufficient and useful to facilitate and support student high school projects. Student mentors also were observed in the classroom being guided by the K-12 teachers, “The mentors continue to look at the data on the website. The truck has higher CO2. VOC is also higher for the truck. The teacher mentions to the students to draw the actual graphs now. The teacher pulls up the screen and draws on the whiteboard there the car and truck data is. She also labels when the vehicle is at idle start and idle stop on the whiteboard. The teacher then begins to tell students that before you leave, have a way to contact your mentor.”

Mentors did provide feedback on areas which they could have used more guidance to develop their skills, “I would have liked more training and help with the teaching and lesson planning side of things. It’s hard to know how much time to plan out for lecturing and activities, especially because it’s so dependent on the class size and teacher and student interest.” These suggestions for improvement map to research suggesting possible outcomes of these types of programs include the development of teaching skills (Nelson et al. 2017).

**Individual Plane**

On the individual plane, mentors report the development of technical skills related to air quality science and monitoring. On the pre and post surveys, student mentors reported a 45% gain in knowledge of air quality science and a 32% gain on knowledge of air quality monitoring technology. One interviewee reported, “I saw... the reasoning behind certain
Table 1: University Mentor Survey Feedback (n = 16)

<table>
<thead>
<tr>
<th>Item</th>
<th>Pre-Assessment</th>
<th>Post-Assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Community Plane (Scale = yes, no)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recommend course to others</td>
<td>Not Applicable</td>
<td>100%</td>
</tr>
<tr>
<td>Interpersonal Plane (1-5 scale, 5 = Highly Useful)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>On-line curriculum</td>
<td>Not Applicable</td>
<td>4.30</td>
</tr>
<tr>
<td>Individual Plane (Scale = yes, no or 1-5 Scale, 5 = Highly Confident)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Knowledge of air quality science</td>
<td>2.80</td>
<td>4.07</td>
</tr>
<tr>
<td>Knowledge of air quality monitoring</td>
<td>2.60</td>
<td>3.43</td>
</tr>
<tr>
<td>Communication Skills</td>
<td>4.07</td>
<td>3.79</td>
</tr>
<tr>
<td>Mentoring Skills</td>
<td>4.33</td>
<td>4.14</td>
</tr>
<tr>
<td>Interest in future K-12 engineering work</td>
<td>Not Applicable</td>
<td>64%</td>
</tr>
</tbody>
</table>

things such as the combustion reactions and knowing that carbon dioxide and water vapor [are] parts of two different reactions.” Another indicated the impact of the course on technical skill level, “Teaching is a great way to learn a topic at a deeper level because you have to understand the topic from different ways in order to teach to students who learn in different ways.”

On professional skills development, mentors’ assessment of quantitative skills was not in line with expectations even though students reported gains in their qualitative comments. Survey results indicated slight declines in communication skills (-7%) and mentoring skills (-4%). However, student mentors reported gains in these areas, “it was definitely helpful for our teaching skills. So we were able to learn how to engage the classroom and if we found that the classroom was getting lulled to sleep, we could bring them back in by tying in current topics related to agriculture.” Also, another commented, “Outreach experience was really enjoyable and I learned a lot about communicating with students.” Again, “This course helped me gain public speaking skills and skills in how to explain technical topics to people who have never heard of the technology before. These skills will become important later on if I ever want to be in a position of management in industry.” Finally, “This course helped me build a lot of important skills. Teaching helped me improve my communication and presentation skills. I had to answer questions on the spot and explain complex topics in a simple way.” Interestingly, there were more comments about the development of teaching than mentoring skills which are related but separate topics.

There were also comments and observations related to shifts in engineering identity. One mentor commented, “I really enjoyed this course, and although I felt uncomfortable to begin the teaching process, this class is leaving a good lasting feeling! I am considering engineering education as a path, and this class has help reinforce this.” One mentor was also observed in conversation with a school district superintendent discussing the benefits of pursuing a K-12 teacher path in the rural school district. Another mentor was observed engaging a classroom teacher about switching post-graduation plans to becoming a math teacher. She also reported later in the day on a follow up call with family members discussing the implications of switching to this career path. Even mentors who did not think of changing
career paths reported growing awareness into their identity in the classroom, “You know I mean I think that they can tell that we're students too. You know we're winging it. We're not teachers and they're respectful and I like that they, you know, they give us an opportunity to grow ourselves. So I think it's interesting because we're much closer to peers with them than we are. Maybe we are peers with them in a way that the teachers are not, right? And you know we're also peers with the teachers in a different way.” On the post-survey, the majority (64%) of mentors indicated that the course increased their interest in doing K-12 engineering education work in the future.

Outcomes similar to the results of this investigation could also be found in the review of the literature including the impact of K-12 outreach on STEM content knowledge and its application as well as communication skills (Zarske et al. 2008). It can be noted in the literature that both of these competencies are important outcomes for ABET accreditation as well (Passow & Passow, 2017).

**Recommendations and Future Research**

Results imply that a year-long course on learning to mentor inquiry learning based projects in K-12 classrooms can develop student mentors’ technical and professional engineering knowledge and skills as well as make changes in their identity as engineers to include notions of engineers as communicators and teachers. The descriptions and outcomes of this study are similar to descriptions of service based learning courses in the engineering education literature (Jeffers et al. 2004). In addition, these outcomes are similar to outcomes recommended for ABET accreditation (Passow & Passow, 2017). Based on these results, this type of course could be recommended as one alternative in a curriculum beyond traditional design courses for the broad development of these types of skills. Future research needs to explore the development of professional skills as quantitative results indicated slight declines in these areas while numerous qualitative results indicated the development of communication skills.

Even though this course is similar to other service learning engineering courses, the course could be improved by adding content similar to courses described in the literature offered by university schools of education. Future research and practice could include a revision of the course to include the requested teaching skills including the development of a lesson plan and classroom management techniques (Nelson et al. 2017). Future studies should investigate the student mentors understanding of teaching vs. mentoring as well as this could drive a need for clarification in training. Future research will also incorporate assessment results from the post-assessment for 2019 to further explicate the impact of the course.

**References**


Thompson, S., Watson, J. & Lyons, J. (2010). Measuring Change In Engineering And Science Graduate Students’ Teaching Efficacy As A Result Of Participation In A Gk 12 Project. Proceedings of the ASEE Annual Conference, Louisville, KY.


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Building a Repository of Instructional and Assessment Techniques for Instructional Module Development System

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Abstract: Instructional Module Development System (IMODS) project aims to assist educators in developing a STEM-based curriculum, even if the educator has not had extensive or formal training in education. The Instructional Module Development System is open-source web-based course design software that presents a framework for representing curriculum, particularly in the areas of STEM, and scaffold users through the process of curriculum development. Research shows that choice of appropriate curriculum and assessment methods are critical in successfully teaching students and having the students retain the information taught (Boice, 2000). IMODS strives to be a tool to assist educators in building a curriculum that follows an outcome-based education process and includes clear learning objectives along with an instructional and assessment plan. To successfully achieve this goal, a variety of educational, instructional, and assessment strategies are required to be integrated into the program. In this paper, we present the design and implementation of a repository of current best pedagogical and assessment practices that are included as part of IMODS. We present our methodology for identification and collection of various instructional and assessment techniques from various top engineering education journals and conferences. We also present the integration of this repository into the IMODS software to present various options to the user when defining the learning objectives of a course. We present the results of the evaluation of the repository constructed and the search feature for instructional and assessment techniques within the IMODS system.

Introduction

The Instructional Module Development System (IMODS) is open-source web-based course design software that presents a framework for representing curriculum, particularly in the areas of STEM, and scaffold users through the process of curriculum development (Bansal, 2015). Research studies show that for 95% of new faculty members, it takes four to five years, through trial and error (the most common method of gaining expertise in teaching), to deliver effective instruction (Boice, 2000). While there are a number of options available to faculty for receiving instructional development training (i.e., training focused on improving teaching and learning), most share similar format, features, and shortcomings. For example: workshops, courses, and seminar series, the most common program structures, are often offered at a cost to the institution, department or individual attendee; delivered face-to-face at specified times; and accessible to a restricted number of persons. Even when interest is high, these factors can become obstacles to participation. Our research goal was to develop a framework for outcome-based course design process and translate it into a web-based software tool that:

- guides individual or collaborating users, step-by-step, through an outcome-based process as they define learning objectives, select content to be covered, develop an instruction and assessment plan, and define learning environment and context for their course(s).
contains a repository of current best pedagogical and assessment practices, and based on selections the user makes when defining the learning objectives of the course, the system will present options for assessment and instruction that align with the type/level of student learning desired.

We have developed the underlying framework for Instructional Module Development System (IMODS) that supports the design of various components of a course such as the learning context, learning objectives, course content, assessments, and instructional techniques of an instructional module (Andhare, 2012; Bansal, 2015). Outcome-based education (OBE) (Furman, 1994; Harden et al., 1999) was used as the principal guide for the development of the IMODS framework. The IMOD system facilitates self-paced instructional development training while the user creates his/her course design with the added benefits of being free to all who are interested, accessible anywhere through a web browser, and at any time that is convenient.

In this paper we focus on the design, development, and evaluation of a repository of instructional and assessment techniques that are connected with learning objectives of a course. The framework ensures that every learning objective is assigned appropriate pedagogical and assessment techniques based on Bloom’s taxonomy’s learning levels and knowledge dimensions that the learning objective caters to. This repository is integrated into the existing IMODS system with search feature for users to browse through available techniques. IMODS system also checks for the fidelity of course design and alignment of various course components: learning objectives, content, assessments, and pedagogy.

Research Objectives
The research objectives of this paper are as follows: (i) design of a repository of assessment and instructional techniques that can be incorporated into a course; (ii) evaluation of effectiveness of the IMODS tool in providing appropriate pedagogy and assessment techniques; (iii) usability of repository of techniques in IMODS tool. We present the methodology for design and development of the repository, evaluation instruments, and analysis of results obtained.

Background & Related Work
A. Outcome-based Education
The emphasis of OBE is on maximizing student performance by carefully designing course outcomes to match the level of learning expected from the students. The focus of OBE is on the product and not on the process (Furman, 1994). Knowledge of Bloom’s Taxonomy helps instructors compartmentalize various aspects of course objectives and design each objective with specificity and precision. Learning is classified into three categories – cognitive (mental skills), affective (emotional growth), psychomotor (physical skills) (Clark, 1999). There are different levels of knowledge and excellence that can be obtained for each of the learning domains and thus we have six domain categories – remember, understand, apply, analyze, evaluate and create. Along with having domain categories, Bloom’s taxonomy also has a mechanism of labeling the actual content – factual, conceptual, procedural, metacognitive (Anderson, 2001). The principles of OBE have already inspired a few models for course design such as – Effective Course Model by Felder, 2011 and Integrated Course Design by Fink, 2003.

B. Web-based tools for Instruction Design
There are numerous web-based tools supporting instruction design. Electronic Performance Support System (EPSS) are a category of systems that help users in improving their performance. They provide an electronic environment that helps users do their job with minimal help and support from others. Thus, it provides a complete range of information, data, tools and guidance to enable users to do their job on their own. The second category of systems are the Learning Management Systems (LMS) that act as online instructors, and sometimes even
replace classroom teachers. LMS is used for administration, documentation, and progress reporting of the student. These systems can be used to provide subject matter and notes to the student, answer queries the student might have about a topic, and even conduct and grade online assessments. The third category are Knowledge Management Systems (KMS) that help with knowledge sharing among people. They help organize knowledge by sharing experiences of users, recording past successes and failures.

In contrast, IMODS (i) guides individual or collaborating users, step-by-step, through an outcome-based education process as they define learning objectives, select content to be covered, develop an instruction and assessment plan, and define the learning environment and context for their course(s); (ii) provides a repository of current best pedagogical and assessment practices, and based on selections the user makes when defining the learning objectives of the course, the system will present options for assessment and instruction that align with the type/level of student learning desired; (iii) generates documentation of course designs; (iv) provides just-in-time help to the user with explanations on how to perform course design tasks efficiently and accurately; (v) provides feedback to the user on the alignment of the course design components (i.e., content, assessment, and pedagogy) around the defined course objectives (Bansal, 2015). IMODS assists the instructor in creating well-defined learning objectives based on its theoretical model - PC\(^3\) model (with appropriate learning domain and domain category from Bloom’s taxonomy) followed by appropriate choice of assessment and pedagogy techniques. To the best of our knowledge there is no tool that provides a repository of assessment and pedagogy techniques. Finding such techniques involves literature search for appropriate publications in journals or conferences of the specific discipline and this is an extremely cumbersome process.

**Theoretical Framework**

The IMOD framework adheres strongly to the OBE approach and treats the course objectives as the spine of the structure. New constructs (not included in prior models such as Mager, 1997; Fink, 2003; Felder, 2011; Streveler, 2011) are incorporated to add further definition to the objective. The work of Robert Mager [11] informs the IMOD definition of the objective. Mager identifies three defining characteristics of a learning objective: Performance – description of what the learner is expected to be able to do; Conditions – description of the conditions under which the performance is expected to occur; and the Criterion – a description of the level of competence that must be reached or surpassed. For use in the IMOD framework an additional characteristic was included, i.e., the Content to be learned – description of the factual, procedural, conceptual or meta-cognitive knowledge; skill; or behavior related to the discipline.

The resulting IMOD definition of the objective is referred to as the PC\(^3\) model (Andhare, 2012). The other course design elements (i.e., Content, Pedagogy, and Assessment) are incorporated into the IMOD framework through interactions with two of the PC\(^3\) characteristics. Course-Content is linked to the content and condition components of the objective. The condition component is often stated in terms of pre-cursor disciplinary knowledge, skills or behaviors. This information, together with the content defined in the objective, can be used to generate or validate the list of course topics. Course-Pedagogy is linked to the
performance and content components of the objective. The types of instructional approaches or learning activities used in a course should correspond to the level of learning expected and the disciplinary knowledge, skills or behaviors to be learned. The content and performance can be used to validate pedagogical choices. Course-Assessment is linked to the performance and criteria components of the objective. This affiliation can be used to test the suitability of the assessment strategies since an effective assessment, at the very least, must be able to determine whether the learner’s performance constitutes competency. Figure 1 shows a visual representation of the IMOD framework. Learning domains and domain categories defined by Bloom’s revised taxonomy (Clark, 1999; Anderson, 2001) are used to describe learner performance. Learning domains are categorized into Cognitive, Affective, and Psychomotor, which are further classified under various Domain Categories (Remember, Understand, Apply, Analyze, Evaluate, Create). Each Domain Category has performance verbs associated to it. Learning objective in the PC³ model is described in terms of Performance, Content, Condition, and Criteria.

**Performance**: is described using an appropriate action verb from revised Bloom’s taxonomy based on the learning domain and domain category.

**Criteria**: Learning objective assessment criteria are categorized as quality, quantity, speed, and accuracy. Criteria for learning objectives are described in terms of one or more of these categories with a criteria value defined or determined later when the assessment is defined.

**Knowledge Dimensions**: The revised Bloom’s taxonomy introduced an additional dimension called the knowledge dimension that was categorized as Factual, Conceptual, Procedural and Metacognitive (Anderson, 2001).

**Topic Prioritization**: The IMODS framework uses a prioritization framework that classifies topics and subtopics of a particular course as one of the following: Critical, Important, Good to know. Achieving the right mix of the three levels of learning (priorities) is essential to planning a good course.

**Methodology**

Our methodology involved an extensive literature search for relevant articles reporting on interesting and innovative assessment and pedagogical techniques. In collaboration with a librarian from our institution we conducted this study and followed these steps. (i) Identification of research databases where relevant articles on education assessment and instructional techniques could be found; (ii) Next step was coming up with the search terms by determining the controlled vocabulary available in the various major databases and coming up with a mapping of the variants of the same term used in different databases. (iii) This was followed by the search strategy based on the nuances of the search engines provided by the different databases. (iv) Filtering out relevant articles from the search results obtained and skimming through the articles to determine relevance. (v) The final list articles obtained had to be processed manually to determine pertinent details about the techniques that can be fed into our IMODS database of assessment and pedagogical techniques.

Controlled vocabulary and thesaurus available in the major databases such as ERIC, Inspec, Compendex EI, and PsycINFO were studied to compile a list of terms related to learning and teaching methods. A subset of the compiled list is shown in table 1. An entry of ‘0’ indicates that the term was not available.

<table>
<thead>
<tr>
<th>Search Term</th>
<th>ERIC</th>
<th>Compendex EI</th>
<th>Inspec</th>
<th>PsycINFO</th>
</tr>
</thead>
<tbody>
<tr>
<td>active learning</td>
<td>active learning</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>adventure education</td>
<td>adventure education</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>autobiography /</td>
<td>autobiographies</td>
<td>0</td>
<td>0</td>
<td>autobiography</td>
</tr>
<tr>
<td>biographies</td>
<td>biographies</td>
<td>biographies</td>
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<td>biography</td>
</tr>
</tbody>
</table>
We included PsycINFO controlled vocabulary for variations on learning and teaching terms. This database was not on our initial list given its psychological focus. Next challenge was to eliminate any terms that would primarily be used in machine learning or Artificial Intelligence there by finding articles not relevant to our theme. In a few preliminary searches we discovered that without the terms “college students” and “engineering education”, learning activities retrieved were too basic to be incorporated into even the freshmen level courses or were in areas other than science and engineering. We also decided that we wanted only the last 10 years of articles. Any quintessential teaching or learning articles would be referenced in the newer articles on learning and teaching methods. For the first part of the research, we wanted to stay with engineering programs where it would be easier for the team to evaluate the active learning and teaching methods presented in the articles.

**Search Strategy:** Most searches started with the basic format for assessment and teaching methods respectively:

- “college students” AND “engineering education” AND [learning term]
- “college students” AND “engineering education” AND [teaching method]

The databases searched were selected based on the number of citations given to the list of terms. When there are less than 100 citations to a term, it might have been more efficient to look at all of those, even if most articles would be inappropriate for our purposes. Using the discipline-specific association digital libraries worked best when searching for articles within a
specific association. Unfortunately, in engineering, articles could show up in any of the association digital libraries. We started with Compendex and Inspec, which are both on the same platform in our university library. One reason for starting here, beyond the high number of citations for our selected terms, was that all of the professional association digital libraries articles are included in the indexing. We acknowledge that there is not 100% overlap, but for our purposes it was a better starting point to quickly build a list of potential articles to include in the database. We next moved to the education databases, ERIC and Education Full Text where many of the practicing educator articles are indexed. This also served to double check for articles in journals and conferences indexed by all four databases. Any article that showed up in the list of citations in more than one database was worth the time to read the article more closely in the methodology and results sections. We saved the ASEE digital library for last since it has a less sophisticated search engine. We still used “college students” but not the “engineering education” because this is all engineering education. This was much slower to sort through articles since there is no way to limit by publication year when the sort is by relevance.

Sample assessment search from ERIC controlled vocabulary search using ProQuest platform:

SU.EXACT.EXPLODE("Teaching Methods") AND SU(evaluation) AND (SU.EXACT("Engineering Education") OR SU.EXACT("Science Education") OR SU.EXACT("STEM Education")) AND SU(college OR university OR "higher education")

We used ProQuest instead of the free ERIC version as it has a more powerful search engine.

Observations on a specific learning method searches in Compendex & Inspec:

- Problem-based learning (PBL) is a classic teaching method that had a surge of innovative changes that has since tapered off.
  - Without College students or related educational level term, results were often too much K-12, not enough college.
    - Search term (PBL OR problem-based learn OR project-based learn) AND "engineering education" AND "college students" retrieved 6 articles for 2005-2015 and same 6 articles for 2009-2019 year range. This is a case of it being too restricted.
    - Search term (PBL OR problem-based learn OR project-based learn) AND ("engineering education" OR "college students") retrieved 824 articles for 2005-2015 and 1012 articles for 2009-2019 year range. This set combines terms that we already know are heavily weighted to K-12. It is often a good strategy to combine this way, but not in this case.
    - Search term (PBL OR problem-based learn OR project-based learn) AND "engineering education" AND (college OR "higher education") retrieved 114 articles for 2005-2015 and 186 articles for 2009-2019 year range. This is about the right size to cull through for useful items. More productive for getting relevant techniques for incoming Freshmen engineering education, one of the subgroups we considered.

- Searches for student learning assessment were extremely restrictive since none of these terms are in the thesaurus or controlled vocabulary.
  - Search term ("student assessment" OR "learning assessment") retrieved 1275 articles for 2005-2015 and 1401 articles for 2009-2019 year range. This was too broad as articles may or may not be linked to specific teaching methods. In this case, the majority of the articles were using mathematical or computer algorithms, not the type of assessment methods we were hoping for.
Figure 2 shows a sample screenshot of the search results. We do continue to find words and phrases to add to our potential search terms, whether those terms are added now or we wait to search them at the end of all our other search terms is determined by how much of a buzzword the term is and if the word has alternate uses or meanings. We are still learning how to quickly and efficiently go through hundreds of articles to find the ones with actual examples of activities and research documentation on the validity or reliability, as well as, have identifiable Bloom’s Taxonomy criteria. Many articles are demonstration projects or are too small to statistically predict learning outcomes or teaching methods efficacy proposed in the article.

**Implementation:** IMODS is an open source web application built using Model-View-Controller (MVC) architecture, Groovy on Rails web development framework, PostgreSQL database, along with Jenkins for continuous integration and Git for version control. The system adheres to the PC³ model ensuring that alignment is maintained between all the components – objectives, assessment and pedagogy.

Along with being intuitive, it provides the user with feedback required during course design. A progress bar is provided to indicate design completion with feedback on missing parts. Figure 3 shows Assessment techniques search feature that allows searching based on specific criteria such as learning domain categories and knowledge dimension, adding an assessment to a learning objective, viewing detailed description of an assessment, and adding custom assessment techniques to the repository. In a similar fashion the tool provides an interface to interact with the pedagogy techniques as well.

**Evaluation**

**Evaluation Study Setup:** Our first study was conducted with 6 undergraduate STEM instructors (4 male; 2 female) were recruited from diverse backgrounds. These participants were given access to IMODS for the design of a course that they teach and deliver during the duration of the study. 2 out of 6 were new instructors, 2 had 1-2 years of teaching experience, and 2 of them had more than 5 years of teaching experience. A mixed-methods approach was taken for our research design to measure participants’ understanding of the outcome-based course design process. A quantitative method comprising of a pre- and post-test was used along with a qualitative method comprising of interviews. Details of our instruments are presented in the following section. Our second study was conducted with undergraduate STEM
students in Software Engineering courses over multiple semesters with 20-50 students. Students use IMODS with a pre-defined list of course-design tasks to be performed with the tool in one-hour. This was conducted as an in-class activity. At the end of the session feedback was solicited from the participants through a Usability survey that is presented in following sections.

**Evaluation Instruments:**

1. **Pre/Post Test:** The pre- and post-test, a survey consisting of questions on OBE and Bloom’s taxonomy in general, was used to determine if there has been any increase in the participants’ knowledge on outcomes-based education. The participants are asked to complete the pre-test before they start using IMODS and the post-test after they have completed a course design. Subset of questions specifically about assessment and instructional techniques are as follows:
   - What are the three domains of learning as specified by Bloom’s Taxonomy?
   - What are the four types of knowledge that learners acquire?
   - List the two different kinds of Assessments.

2. **Interviews:** The focus of the interviews was to get as much information as possible regarding the process of course design as a whole, the problems participants faced while developing the course, their opinion on all aspects of the process – with special focus on learning objectives and the selection of techniques for assessments and pedagogy. Complete list of questions used in the interview is provided at Raj, 2018. Following are related to user’s experience with the repository of techniques.
   - Was the tool helpful in the course design process? How?
   - What is your understanding of the knowledge dimensions of the topics?
   - Do you think the choice of assessment/pedagogy techniques presented for your course are appropriate?
   - Can you provide a reflection on how the course designed would help in achieving expected student outcomes?
   - What do you think of the provided support and help documentation?

3. **Usability Survey:** This questionnaire contains questions for the participant regarding usability of the tool. The questions are designed on a Likert scale – Strongly agree, agree, neutral, disagree, strongly disagree. Some of the questions related to the repository of techniques in the survey are as follows. Full list is available at Raj, 2018.
   - The titles for assessment and pedagogy techniques were self-descriptive.
   - The description of the assessment and pedagogy techniques was clear.
   - The documentation produced (assessment plan and instruction plan) for assessments and pedagogy is satisfactory.
   - The selection available for the assessment and pedagogy techniques is satisfactory.
   - It is easy to define custom assessment and pedagogy techniques.
   - The application was easy to navigate.

4. **User Testing:** User testing was done with a student in an undergraduate class. Never having had any teaching or course design experience, they simply had to follow the given instruction to create a complete course design. They were given one hour to complete all the tasks and at the end of the session, students responded to a Usability survey with the same questions mentioned above.

**Results and Discussion**

Results of the evaluation study are presented here.

A combination of pre and post tests was used for this particular evaluation, in combination with in-person interviews. There were six participants in the study and their results (scores out 100) are shown in the table 2. There is an overall increase of 23.16% in the knowledge of the instructors after using the tool. From the data collected from 54 participants this year, 72.3%
agreed that the selection of techniques available for both pedagogy and assessment was satisfactory (figure 4) and 61.1% agreed that the titles used for the techniques are self-explanatory (figure 5). But only 57.4% of the total participants agreed the description of the techniques to be clear (figure 6).

**Table 2: Pre/Post test results of participants**

<table>
<thead>
<tr>
<th>Participant</th>
<th>Pre-test Score</th>
<th>Post-test Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>47.5</td>
<td>69.17</td>
</tr>
<tr>
<td>2</td>
<td>47.5</td>
<td>72.5</td>
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<tr>
<td>3</td>
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<td>98.33</td>
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<td>4</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>5</td>
<td>69.17</td>
<td>75</td>
</tr>
<tr>
<td>6</td>
<td>70</td>
<td>85</td>
</tr>
</tbody>
</table>

For the interview question, “Do you think the choice of assessment/pedagogy techniques presented for your course are appropriate?”, the responses received are shown in table 3. Almost all the participants wanted a generic assessment technique – Assignment. Thus, 33% of the participants were not satisfied with the choice of techniques presented to them. One major flaw turned out to be that the repository did not contain any techniques for the CREATE level domain category. For the question, “What do you think of the provided support and help documentation? Which of the help features did you/would you use?”, the responses received are shown in table 4. Based on the study and the participants’ feedback, it was clear that they preferred the videos (a short 2 min video), rather than reading through textual information.

**Table 3: Responses about “Repository of Techniques”**

<table>
<thead>
<tr>
<th>Participant</th>
<th>Yes</th>
<th>No</th>
<th>Sparked new ideas</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>2</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>3</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>4</td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>5</td>
<td>x</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>6</td>
<td>x</td>
<td>✓</td>
<td>x</td>
</tr>
</tbody>
</table>

**Table 4: Responses about “Support Documentation”**

<table>
<thead>
<tr>
<th>Participant</th>
<th>Video</th>
<th>Information Tab</th>
<th>User Manual</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>2</td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>3</td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>4</td>
<td>✓</td>
<td>x</td>
<td>✓</td>
</tr>
<tr>
<td>5</td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
<tr>
<td>6</td>
<td>✓</td>
<td>x</td>
<td>x</td>
</tr>
</tbody>
</table>

**Conclusions and Future Work**

The data collection for building the repository is underway through an extensive literature review process. The initial sets of techniques identified for the repository (about 50 assessment techniques and 45 instructional techniques) have been loaded and reported in this paper. Our research team is continuing to identify more techniques and populating them into the database. Future work will include conducting a full-text search, using citation tracing of foundation articles to further identify relevant articles, and searching on open access sources for relevant articles. The database design is general enough to accommodate new articles found and we do not anticipate a need to revise it.
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Acknowledgements
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Abstract: The South African Society for Engineering Education (SASEE) was established in 2011 with a view to building a national Community of Practice (COP) for supporting engineering education (EE). Collectively addressing the well-reported global challenges in EE, such as high attrition, poor throughput and concerns about graduate abilities, SASEE has produced 180 full papers and extended abstracts across four conferences, from 2011 to 2017. As part of a larger research project, a review of all SASEE contributions was conducted using a mixed-methods approach, including the use of Legitimation Code Theory to differentiate between authors’ focus on knowledge, knowers, both or neither. Results reveal a general shift from quantitative approaches looking at access and retention to questions of identity, diversity and professionalism. This paper offers a useful lens for the international community on the development of a national engineering educator COP.

Introduction

In response to significant shifts in social, political, economic and technical arenas, EE in South Africa (SA) is adapting to achieve a more equitable and just society. Higher Education (HE) is tasked with educating increasing numbers of school leavers in the 15 public institutions which offer the three key professional qualification levels in the engineering domain described by the Washington (Engineer), Sydney (Technologist) and Dublin (Technician) Accords. The purposes of the engineering qualifications can be differentiated according to a conceptual-contextual or professional-occupational continuum (Paxton & Schoombie, 2011), following guidelines for the development of holistic Graduate Attributes (GAs) (IEA 2013).

The challenges facing engineering educators in SA are echoed in global literature: overfull curricula, increasing diversity and enrolment numbers, and a changing engineering workplace (Fraser et al., 2011). With national goals to meet scarce skills demands “vital...to the social and economic development of the country” (Jordaan, 2011), engineering educators post-1994 initially began to pay particular attention to questions of high attrition (Pocock et al., 2011), low retention and poor throughput rates (Graham & Walker, 2011, 2015) as a result of the “mixed quality of schooling outcomes” (Himunchu et al., 2017) for students entering HE. Early initiatives focussed on assisting students “in making the transition to university” (Grayson, 2011), which has been exacerbated by curricular shifts in the school education sector. The implications of accessing tertiary EE with poor school mathematics/ science proficiency has led educators to question what is required to enable educational success, given its relationship to that of...
‘access’. Wally Morrow (2009) differentiates between formal, democratic, equitable access and that of ‘epistemological access’ to society’s ‘knowledge goods’ - access to forms of disciplined inquiry and the epistemic values of particular fields. This requires a view of the HE mandate as an acknowledgement of the relationship between knowing, doing and being (Knobbs et al., 2013). From the holistic development of professional skills to “make students more employable” (Israel, 2011), to embedded academic literacies approaches (Simpson & Bester, 2011), problem-/project-based learning initiatives (Case et al., 2013), supplemental instruction (O’Hara & Pocock, 2011) and community-engagement opportunities (Ramsuroop, 2011), engineering educators in SA have been grappling with ways to improve engineering student success - despite increasing workloads and lack of recognition for pedagogic innovation (Jawitz, 2013).

This paper has emerged as part of a faculty research project at a traditional, research-intensive university, seeking to make recommendations for a faculty teaching practice guideline in the face of the preceding challenges. The biennial South African Society for Engineering Education (SASEE) conference proceedings as of 2011 were a logical starting point for the SA review, since SASEE is the only body of its type in SA. Established in 2011 with a view to fostering excellence and innovation in EE, SASEE members (educators who are themselves engineers, as well as all the complementary educators that scaffold the EE project) have a participatory, dynamic, ‘social learning system’ view of their emerging ‘Community of Practice’ (Wenger, 2010). The SASEE biennial engineering education conference, the workshops and forums in interceding years, and the inclusion of international EE experts and industry are opportunities through which the society is building its COP in SA. Given the combined REES/SASEE 2019 conference, this paper presents an analysis of SASEE proceedings and illustrates the birth and development of a national COP dedicated to improving the access-success relationship in EE.

Conceptual Framework

The International Engineering Alliance (2013) Graduate Attributes (GAs) clearly frame EE objectives holistically, including specifications for knowledge, skills and practices in contexts involving stakeholders, society and resources. The first engagement with both the SA and international literature review suggested the need for a conceptual framework that took both disciplinary knowledge and stakeholders in the HE space into account. A theoretically-informed, but practically illustrative, framework for educators is that of Legitimation Code Theory (LCT), which enables researchers to interrogate and reveal the organising principles underpinning ‘knowledge practices’ (Maton, 2014). This paper uses Specialisation, which is about what counts: What is “the basis of achievement” in a field of practice (ibid., p. 45)? Is it about knowledge (epistemic relations) or knowers (social relations), both or neither? Depicted as two relational continua on a Cartesian plane differentiating between epistemic relations (ER) and social relations (SR), the Specialisation Plane gives us four quadrants of ‘legitimacy’ (figure 1):

- A knowledge code (ER+, SR-) sees practices as legitimated, or primarily underpinned by knowledge.
- A knower code (ER-, SR+) is legitimacy based on attributes/disposition of knowers.
- A relativist code (ER-, SR-) means that a practice is not specifically legitimated as a result of the knowledge base, nor the attributes of the knower.
- An elite code (ER+, SR+) is indicated where the practice demonstrates legitimacy based on the knowledge base, as well as the disposition of the knower.

As an example, figure 1 also captures the analysis of an unpublished survey (following a SASEE curriculum workshop in 2012) of engineering staff and industry partners’ views of the GAs (formerly called Exit Level Outcomes). Most participants regarded the Knowledge (2) and Tools (5) outcomes as a knowledge code, with Design (3) and Investigation (4) as dependent on both having the knowledge and appropriate attitude (elite code), while all the remaining outcomes (6-10) predominantly relate to practices dependent on being a certain kind of knower - in other words, having the right disposition to be able to recognise context, communicate appropriately, understand engineering in society, work as a team and so on. These practices
are not directly transferable or generic ‘skills’; rather, they are related to induction into the practices of a particular community. Given the focus on enabling access to the ‘epistemic values’ and practices of a profession, both dependent on forms of knowledge and kinds of knower dispositions, Specialisation can illuminate how the EE community in SA sees its role.

Methodology

The review of SASEE 2011 - 2017 biennial conference literature has seen a mixed-methods, inductive-deductive approach across three phases. 180 full papers and extended abstracts were downloaded from the SASEE website and captured in an online spreadsheet shared among the four researchers. ‘Open’ coding of all main and sub-themes led to broad categorisations, including Teaching, Learning, Assessment, Curriculum, Support, Technology, Engineering Knowledge, Engineering Practice and ‘Soft Skills’. A remaining category, labelled ‘General’, saw themes such as pathways, identity, community outreach and statistical analyses of success rates. These categories enabled the allocation of topic tags to the literature review spreadsheet, making it easier to quantitatively cluster and qualitatively cross-reference the papers. Additional information was recorded, such as engineering discipline, author, academic context, and core idea. The first phase analysis saw themes across the education ‘pipeline’ from access and enrolment through teaching and learning, to those around the profession.

The second quantitative phase entailed capturing the top 100 predominant thematic terms (drawn from all the abstracts) in schematic visualisations with word cloud generators. Common words such as ‘university’, ‘student(s)’ and ‘engineering’ were omitted. During this phase the research team observed that many key terms were not necessarily as a result of conference themes or streams. The reading of all papers revealed different approaches to EE practices and research, as well as a distinct divide between a focus on enabling access for whom or to what. Researcher familiarity with the LCT Specialisation Plane led to a decision to employ the instrument in phase 3. The plane was used as a framework to map the full papers and extended abstracts according to the definition of the four codes as illustrated in table 1, and which will be discussed in the following section:

Table 1: LCT Specialisation plane Translation

<table>
<thead>
<tr>
<th>Knowledge</th>
<th>Elite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detailed disciplinary or technical knowledge</td>
<td>Teaching &amp; learning practices that relate kinds of knowledge to knowers, and vice versa</td>
</tr>
<tr>
<td>Curriculum from a knowledge perspective</td>
<td>Detailed theory-practice integration which takes context into account</td>
</tr>
<tr>
<td>Educ./engineering/other forms of disciplinary knowledge framing research/practices</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Relativist/General</th>
<th>Knower</th>
</tr>
</thead>
<tbody>
<tr>
<td>No explicit references to forms of knowledge, nor kinds of knowers</td>
<td>Kinds of stakeholders &amp; Dispositions/attributes (soft skills, employability, professionalism)</td>
</tr>
<tr>
<td>Quantitative studies focussing on statistics for throughput, success, access etc.</td>
<td>Motivation &amp; engagement;</td>
</tr>
<tr>
<td></td>
<td>Social conditions, identity &amp; transformation</td>
</tr>
</tbody>
</table>
Discussion

The first-phase ‘pipeline’ analysis was based on tagging each paper according to predominant thematic terms. We separated ‘conceptual approaches’ to the engineering education research and development of the field (including staff development) from the more practice-based and statistical studies linked to student progression through the pipeline. Some papers were allocated to more than one category, and the number of papers per category was calculated as a percentage relevant to the total number per year.

Figure 2. SASEE Proceedings thematic shifts according to pipeline classification

One can see a COP clearly addressing ways to look at the problem in 2011, and this culminates in a great number of research and development papers in 2013, possibly stimulated by the conference theme: “Teaching professionals / Professional teaching: towards an ethical, efficient and engaged engineering education”. Quantitative studies on access, retention and success dominated in 2011, followed by a focus on forms of academic support as well as a focus on curriculum and knowledge. By 2017 we see a distinct shift towards the end of the pipeline, with questions around assessment, the use of technology and the nature of the profession beginning to dominate, in response to the conference theme: “Engineering education in transition: Responding to a changing HE landscape”. The Phase 2 word-cloud analysis (not represented here) provided the methodological impetus to use the LCT Specialisation Plane (captured in figure 2), and these findings are discussed in the following Specialisation Code sub-sections, beginning with the relativist code and ending with the holistic ‘elite’ code where the synergistic aspects of knowledge and knowers are considered in combination.

Relativist/General code

The largest category (n=74) comprises papers and extended abstracts where there is no specific focus on forms of knowledge (whether disciplinary, technical or professional) and no specific focus on kinds of knowers. The Relativist/General code has been applied to quantitative studies tracking enrolment, retention and performance statistics, as well as those using technicist or scientific methodologies to investigate ‘knower’ issues. By 2015, we find papers reporting on the use of technology without a nuanced or contextualised view of the context, and these have also been coded as relativist.

Figure 3. SASEE Proceedings specialisation code analysis
Knowledge code

Given the predominance of mathematical, natural and engineering sciences in the undergraduate engineering curriculum, it is rather surprising to find only 12 papers alluding to a nuanced and problematised view of engineering education from a knowledge basis. In 2011 we see explicit reference to threshold concepts in chemical engineering (around the topic of sustainability) where it was found that “the process of learning about sustainable development is a complex and transformative experience” (Sibanda et al., 2011). Smith (2013) follows with a paper on the conceptual gaps between 1st and 2nd year when concepts change context, and Wolmarans (2013) takes us into the specific nature of knowledge in engineering design. Wolff (2015) takes the analysis of industry-based engineering problem solving back to educators by focussing of forms of engineering disciplinary knowledge, how they are acquired and applied. In 2017 we find a report on the nature of technical knowledge with which graduates engage (Basson, 2017). From a curriculum design perspective, we see a partial focus on knowledge in a small number of papers, such as the principled-procedural distinction in curricula (Paxton & Schoombie, 2011), a conceptual structure for interdisciplinary learning (Luckan, 2013), curriculum pathways (Grobler, 2015) and holistic curriculum design (Chetty & Naicker, 2017).

An interesting observation is the sheer number of papers engaging in inter/multidisciplinary research by drawing on forms of knowledge from other fields, whether from a methodological or theoretical perspective. We find researchers using complexity theory (Forsman et al., 2011) to look at retention; cybernetics to look at the teacher-student relationship (Baron, 2015); neuroscience to understand the ‘presence’ of deep learning (Lazanas, 2017); Machine Learning approaches to determine student support needs (Taodzera et al., 2017) and Control Theory to map a lecturer’s approach to enabling theory-practice integration (Auret & Wolff, 2017).

Interdisciplinary knowledge is also evident in the number of papers drawing on Academic Literacies or Discourse theories to explore questions of ‘academic citizenship’ (Knott et al., 2011), scaffolding learning towards greater cognitive demand (Simpson & Bester, 2011), and the crucial question of enabling meaningful access to the practices of engineering through its discourse (Snell & Woollacott, 2011).

Educational technology papers dominate in 2017, but do not necessarily engage with forms of technological knowledge, nor disciplinary knowledge underpinning the creation and use of technology (which is, in fact, what engineering does!). However, Luckay & Collier-Reed (2011) introduce us to the Technological Profile Inventory where qualitative, interview-based data from 435 participants found that technology is either viewed as an artefact or related to a process “involving the application of knowledge, design, and production in the development and use of objects, systems, and processes to satisfy human needs” (ibid., p. 142).

Knower code

The second largest and most complex category across the four conferences (n=69) is the knower code, which was allocated to all papers explicitly focussing on stakeholders in engineering education (mainly students and staff) where attributes, social conditions, identity, engagement and employability were foregrounded. The predominant theme here is one of enabling access beyond simply that of physical access. To pick up from the previous point on technology, Deacon et al. (2017) establish that MOOCS (Massive Open Online Courses) are “expanding the breadth and access of university course provision”. The pipeline analysis (figure 2) shows a significant shift in 2015 to the integration of technology into the teaching, learning and assessment space. We see papers focussing on improving technological access to labs (Fernandes et al., 2017), analysing student engagement with online resources so as to understand learner behaviour (Gilmore et al., 2017), and enabling anonymised, immediate classroom feedback through backchanneling (Collier-Reed, 2015). Technology was a natural response to the #feesmustfall (#FMF) protests in 2015 and 2016, when universities had to close, classes were cancelled and exams postponed (Belford, 2017). Enabling access to e-resources offered “convenience, individual learning, … a sense of community and greater all round participation” (ibid., p. 22).
The unspoken impetus for the knower code papers is articulated by Graham et al. (2017): The “need to explore factors that mitigate or promote articulation, as removing obstacles that hinder access, articulation, mobility and progression of students can only positively contribute to the development of a more socially just society.” The SASEE COP initially sets out with a generally deficit approach to learners as ‘underprepared’ and ‘ill-equipped’ across several statistical access/retention/success papers. However, Swart (2011) sets the tone for a more nuanced examination of conditions for learning by looking at stress and anxiety, and a small, qualitative study in 2017 highlights conditions for ‘inclusion’ and ‘belonging’ (Kanjee & Campbell, 2017). Gender makes its appearance in 2015 with a study on roles in a laboratory practical (Simpson & Bester, 2015). Several papers look at forms of learning from the student perspective, including learning styles (Street et al., 2017), peer-learning (Van Niekerk & Mentz, 2013), teamwork approaches (Schreve, 2013), constructivist and social learning (Nudelman, 2017), and learning via gamification (Heymann et al., 2017; Greeff et al., 2017).

The theme of discourses and literacy practices introduced in the Knowledge code section continues here with papers explicitly foregrounding questions of access. In his paper on plagiarism, Barris (2013) argues for an agential approach, since students experience “alienation from the academic process, and from the value system [associated with] academic staff, but [which they] do not identify with at a personal level”. Literacy practices are a significant gateway to progress and success (Simpson, 2011). These papers mark the introduction of a strongly reflective approach (Kuriakose, 2013) to EE, as educators begin to engage with deeper issues around roles in our SA context. The 2015-2016 student protests raise questions around ‘whose knowledge’, and hence the first mention of decolonising the curriculum in 2017 (Kanyarusoke & Ngonda, 2017) with a call to address “curriculum, race relations, teaching methods and languages of instruction”. Mkonto et al. (2017) propose that “in the context of strong economic, social, political, and historical inequalities, universities in SA should not see first-year students as a homogenous entity”.

The reflective turn is picked up by the engineering academics themselves who are increasingly reporting on professional development initiatives (Mhlanga et al., 2013) aimed at making staff aware “of the problems and obstacles that students...face” (Lourens, 2017). Blaine (2017), for example, engages in an honest reflection on her attempt to develop students’ problem-solving abilities. We see technology again, this time as a reflective tool - intended as a medium for authentic self-reflective feedback by students - which simultaneously enables the development of technical skills (Jordaan & Jordaan, 2017). In a thermodynamics assignment requiring student reflection, Kauchali & Woollacott (2017) report a mismatch between teacher expectations of reflective capabilities and the students’ perception that a process description was required.

The final sub-theme in the knower code category is that of the profession itself, with a small number of papers looking at employment and employability (Podges & Kommers, 2013; Nudelman, 2015; Basson, 2017; Case et al., 2017). The key finding in a paper on how work placement experiences affect student perceptions of competency found that although “professionalism is a frequently bandied-about aspirational value for workers... its enactment within professions [is] underpinned by deep ideological strains which play a part in the legitimation of particular kinds of knowledge, practices and even identities that are deemed acceptable within a particular profession” (Ngonda et al., 2017).

**Elite code**

Essentially, the purpose of professional EE is to enable the development of the full range of GAs, which include forms of disciplinary knowledge and methods, technical skills, and socially-situated practices (communication, management and ethics) determined as necessary by the field. One could argue that the elite code encompasses these GAs. A total of 25 papers were assigned to this category. In 2011, we see a nuanced, reflective paper on enabling engineering identity development in the mathematics classroom (Craig, 2011); a flexible, portfolio approach to competency evidence against exit level outcomes (Smithers & Lagrange, 2011); a
phenomenographic study (Campbell & Smit, 2013) which found that factors impacting on success included “structure related factors, student related factors and disciplinary knowledge factors.” Motala (2017) describes his award-winning teaching initiative which was “used as a means to develop students’ social, environmental and ethical awareness, as well as to foreground student subjugated knowledge through the lens of geomatics”.

Conclusions

The review of the national contributions to the SASEE COP using LCT Specialisation suggests a consistent knower code across the four conference cycles. It seems clear that the COP is concerned about finding ways to understand students, their needs, obstacles, and opportunities for engaged learning. What does appear to have shifted is the approach to EE research, with educators engaging in “more rigorous [qualitative] research” (Kloot, 2017), consciously drawing on a range of theories and theoretically-informed methodologies. This was highlighted as a need at the 2013 conference, where Simpson (2013) called for EE researchers “to engage in theorization of the specific events and practices that make up the myriad teaching and learning experiences within the context of the engineering sciences”.

The low number of papers in the knowledge and elite categories suggests that the lack of theorisation around the nature of knowledge (and implications for its acquisition and application) deserves more attention, given the statistical studies in the relativist/general category which do not necessarily paint a picture of success. Most of the success stories are fairly small, ‘victory narratives’, which - albeit indicating small signs of success - may not always apply to our predominantly large-class, under-resourced contexts. The challenges of diversity, massification and retention are not limited to the SA context. This research could offer the international community a useful lens and analytical tool with which to examine and succinctly capture the development of a Community of Practice over time.

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How do engineering lecturers perceive the Scholarship of Teaching and Learning?

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Abstract: The Scholarship of Teaching and Learning (SoTL) forms the basis of the Teaching and Learning (T&L) Policy at Stellenbosch University, a research-intensive university in South Africa. Through the policy, the professionalisation of teaching practice is promoted by encouraging academics to engage with progressive levels of scholarly practice in T&L. In this study, the perceptions of SoTL, and how these relate to the professionalisation of an academic’s teaching practice, are explored and presented, through analysis of interviews with purposefully selected lecturers from the Faculty of Engineering. Their perspectives are elucidated through guided, thematic analysis of the interview transcripts. The results show that participants agree that reflective practice should, at least, be part of their scholarly approach to teaching. However, the requirement to professionalise their teaching practice through further SOTL engagement is not seen as critical or necessary. Additionally, institutional recognition is only awarded once academics engage at the teaching scholar level.

Introduction

Most academics start their teaching career with little to no formal training or knowledge of pedagogy (Oreta, 2016; Boud & Brew, 2017). Their initial ideas of how to teach are typically based on their personal experiences as a student, along with their assumptions about how students learn and what good teaching looks like (Case, 2015). Their perceptions develop informally as they build their teaching practice, through reflecting on approaches that they have tried or been exposed to, that promote (or stagnate) student learning (Leibowitz, 2014; Young, 2008). Since the 1990s, the Scholarship of Teaching and Learning (SoTL) has emerged as a new paradigm for considering the role of teaching as a legitimate part of academic scholarship (Boyer, 1990). Currently, SoTL is widely promoted within academia as underpinning excellent teaching practice (Tight, 2017). Nevertheless, SoTL’s road to mainstream integration in academia has not been smooth and has been continually met with resistance (Schroeder, 2016; Boshier, 2009).

The current teaching and learning policy at Stellenbosch University (SU), a research-led South African university, uses SOTL as its foundation, promoting the professionalisation of academics’ teaching roles (Stellenbosch University, 2018). However, in order for policy to be transformed into practice, it is crucial that there is understanding and buy-in from the respective stakeholders (Marshall et al., 2011). This requires strong leadership that is appropriate for its context. Quinlan (2014) presents an educational leadership model that promotes “leadership of teaching for student learning and development.” She proposes that it is critical for leaders to understand the specific needs and idiosyncrasies of their departmental microcosms within a university, and to engage and work with staff members in co-creating holistic learning environments. It is crucial that academics feel that their voices are heard and that trust is established in order to build a sustainable and effective T&L framework.
The revision of the SU T&L policy in 2017 resulted in a document that should support and guide academics in professionalising their teaching practice, based on sound principles of SOTL. However, whether or not academics align their behaviour with the new policy is dependent on sound leadership principles, as recommended by Marshall (2011) and Quinlan (2014) above. This study examines the views of academics, from the Faculty of Engineering at SU, regarding their perceptions of SOTL and how this relates to the professionalisation of their teaching practice. Implications for the meaningful implementation of the SU T&L Policy are deduced by reflecting on their views against this backdrop.

Background and context

Stellenbosch University’s T&L Policy states as a point of departure that SoTL is viewed as a key aspect in informing and professionalising general teaching practice. The policy identifies and describes progressively scholarly levels of teaching practice for academics, as listed in Table 1.

<table>
<thead>
<tr>
<th>Levels of teaching practice</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Reflective practitioner</td>
<td>Teaching is thoughtful, designed to engage students and promote learning, and continuously improved through reflection on past practice and current context</td>
</tr>
<tr>
<td>Scholarly teachers</td>
<td>Reflective practitioner teachers start consulting educational literature, specific to their field, and bringing pedagogy into their teaching practice</td>
</tr>
<tr>
<td>Teaching scholars</td>
<td>Scholarly teachers go further to reflect, design, implement and evaluate teaching interventions in their classrooms, and start to share their practice with other teachers in teaching forums and conferences. This category extends to incorporate educators who engage in educational research and publish their work in peer-reviewed media</td>
</tr>
<tr>
<td>Leaderly teaching scholars</td>
<td>Teaching scholars start to take leadership roles in that they promote and facilitate the advancement of teaching and learning excellence in teams within the university and educational context nationally and internationally</td>
</tr>
</tbody>
</table>

The perception of SoTL amongst academics, especially those at research-led universities, is often that it is a research field with lower status and not worth the effort, or it is seen an “easy out” for academics who do not have strong disciplinary research profiles (Boshier, 2009; Case, 2015). Ironically, for those who do delve into the field, the steep learning curve associated with adopting a new body of knowledge, with an unfamiliar discourse and research methodologies, presents a significant challenge that often discourages them from engaging in a meaningful way with the literature or developing their SoTL practice (Adendorff, 2011). The purpose of this research project is to investigate the different perspectives that academics, in SU’s Faculty of Engineering, hold and to reveal how they experience SoTL in their daily work environments. This study forms the pilot stage of a longer term project that is focused at promoting and improving engagement in SoTL in a synergistic manner, so that it is seen as a practice that supports an academic’s teaching role and career development.

This study aims to answer the research questions:

How do SU engineering academics perceive SoTL in the daily work environment?

How do SU engineering academics perceive the professionalisation of their teaching practice, and particularly, how does it relate to SoTL?

Literature review

Research on teaching has a long history in the context of school teachers and their pre-service training; however, research on higher education teaching is relatively lagging (Case, 2015; Quinlan, 2014). The proposed study draws on primarily on the body of knowledge that forms
the SoTL. SoTL provides the conceptual framework and thus the theoretical lens through which the perspectives of academics is explored.

SoTL first gained prominence in higher education through Boyer’s seminal work (Boyer, 1990) and from this work, a SoTL movement emerged in the US. Boyer’s report refers to four separate yet overlapping functions of scholarship: Scholarship of discovery, Scholarship of integration, Scholarship of application and Scholarship of teaching. He argues that knowledge is acquired through research, through synthesis, through practice and through teaching, and that these aspects “dynamically interact, forming an interdependent whole.” His full description presents a holistic and inclusive view of what it means to be an academic scholar, where theory informs practice, and is, in turn, born of practice.

Research following on Boyer’s seminal work, introduced various distinctions in SoTL activities that differ in intent and outcome. Most views of SoTL include both drawing on research to inform teaching practice, as well as producing new knowledge related to teaching and learning. However, even though the exact nature of SoTL has been debated extensively over the past two decades, a wide range of definitions and descriptions exist. There is little consensus as to its boundaries or scope, and so its value is still questioned and interrogated (Boshier, 2009; Case, 2015; Geertsema, 2016; Hutchings, 2007, 2010; Tight, 2017; Trigwell et al., 2000; Witman & Richlin, 2007). Studies relating to engineering specific contexts focused on defining, implementing or assessing SoTL for teaching awards in these environments, but did not explore the lived experiences of academics in engineering faculties (Felder & Hadgraft, 2013; Streveler, Borrego, & Smith, 2007; Wankat et al., 2002)

Hutchings (2013) describes the principles and practices of SoTL as teaching that is informed by scholarship, that can be improved through reflective practice, systematic inquiry, critique and collaboration. Distinctions are drawn between scholarly teaching and the scholarship of teaching (Case, 2015; Felder & Hadgraft, 2013; Witman & Richlin, 2007). Scholarly teaching is limited to consulting the SoTL literature to guide teaching practice, conducting systematic observations, reflecting on practice, analysing outcomes and obtaining feedback on teaching. The scholarship of teaching, however, refers to systematic inquiry into teaching practices, where findings are shared at conferences, and published in peer-reviewed journals in order to advance research and practice in teaching and learning. These analytical distinctions clearly align with the differentiated levels of teaching practise provided in Table 1, taken directly from the SU T&L policy.

Social constructivism is based on an assumption that reality is constructed by individuals, within a specific social context, through their experience and interaction with concepts in that context (Cousin, 2013). Additionally, construct alternativism aligns with personal construct theory, that recognises that as a person engages with and experiences a phenomenon, they will continually reconstruct their understanding and perception of this concept (Zuber-Skerritt, 2001). These paradigms form the theoretical framework for the study, where the study strives to reveal how academics construct their perspective on SoTL and the professionalisation of their teaching practice in situ.

Methodology

A dual methodological approach was employed, based on phenomenology, and informed by some of the features of phenomenography (Collier-Reed & Ingerman, 2013; Creswell, 2012; D. Marshall, Summers, & Woolnough, 1999). Phenomenology looks to reveal the commonality in experiences of a phenomenon amongst a group of individuals, in order to construct a rich description of the experience. Phenomenography looks to reveal distinct differences in the ways in which a group views a specific phenomenon, in order to present different perspectives of the same concept. Phenomenography has been used in learning research to present different ways in which students view a key concept, such as the concept of force (Collier-Reed & Ingerman, 2013). Marshall et al. (1999) used it to describe engineering students’
perceptions of learning. It has also been used to explore how academics approach SoTL in a study at an Australian university (Trigwell et al., 2000).

**Methods**

The data collection method most commonly used in phenomenology is the semi-structured interview. Typically only a small number of interviewees are required, 5-10 people (Creswell, 2012). A slightly larger group is used for phenomenography, 10-20 interviewees, in order to provide enough data to form clear critical aspects from which qualitatively different categories of perspectives are constructed (Tight, 2016). In both cases, it is appropriate to deliberately select project participants in order to cover as wide a range of perspectives as possible. Furthermore, it is necessary to select participants who are known to have some degree of experience with the phenomenon being studied.

Thus, a small group of 10 academics, with varying degrees of teaching experience and interaction with SoTL, was selected from different departments in the Faculty of Engineering. The academics were purposefully selected, in consultation with the faculty Vice-Dean: Teaching and Learning, to provide diverse representation across the categories and descriptors listed in Table 2. Gender and racial diversity representation was also sought across the participant group. As participation was voluntary, not all of the descriptors listed for each category were represented in the final group of consenting participants. Ethical (TL-2018-7930) and institutional (IRPSD 1086) clearance for the study was granted through SU’s relevant departments.

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>DESCRIPTOR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Position</td>
<td>lecturer, senior lecturer, associate professor or full professor</td>
</tr>
<tr>
<td>Experience</td>
<td>&lt;5, 5-10, or &gt;10 yrs teaching experience</td>
</tr>
<tr>
<td>Department</td>
<td>Process (Chemical), Civil, Industrial, Mechanical &amp; Mechatronic, Electrical &amp; Electronic</td>
</tr>
<tr>
<td>SoTL engagement</td>
<td>formal &amp; published, formal not published, or informal</td>
</tr>
</tbody>
</table>

One-on-one interviews were conducted with participants, scheduled for an hour each. The interviews typically began with an informal conversation where the participants were asked why they chose a career in academia and how they came to the position they held at SU. Following this, the descriptions of the different scholarship levels for teachers, as listed in Table 1, were shared with the participants and they were asked to speak about their teaching practice and experience with SoTL, while taking these teaching levels into account. Audio from each of the interviews was recorded and transcribed.

A guided thematic analysis approach was used to analyse the data, as described by Freeman (1996) and Creswell (2012). With this approach, the researcher determines coding categories or themes for the data a priori by consulting published literature. Thereafter the researcher fully familiarises themselves with the data, in this case the interview transcripts, and starts to code the data according to the a priori themes. As the process of analysis unfolds, themes are modified or added through the researcher’s interaction with the data.

The a priori themes for this analysis were based on two studies regarding approaches and experiences of SoTL in academia in general. The first study used to identify themes was conducted by Trigwell (2000), where five categories that distinctly describe different views of SoTL are offered, as shown in Table 3. Secondly, Adendorff (2011) identified challenges that academics, across different faculties at Stellenbosch University, encountered during their experience and engagement with SoTL, as shown in Table 4. These perspectives form the analytical framework for the study.
In order to confirm the validity and authenticity of the results, the results were presented to the participants and they were given the chance to discuss and give input or make recommendations before the results are finalised.

Table 3 Categories of different experiences of SoTL (Trigwell et al., 2000)

<table>
<thead>
<tr>
<th>The scholarship of teaching is about</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. knowing the literature on teaching by collecting and reading that literature.</td>
</tr>
<tr>
<td>B. improving teaching by collecting and reading the literature on teaching.</td>
</tr>
<tr>
<td>C. improving student learning by investigating the learning of one’s own students and one’s own teaching.</td>
</tr>
<tr>
<td>D. improving one’s own students’ learning by knowing and relating the literature on teaching and learning to discipline-specific literature and knowledge.</td>
</tr>
<tr>
<td>E. improving student learning within the discipline generally, by collecting and communicating results of one’s own work on teaching and learning within the discipline.</td>
</tr>
</tbody>
</table>

Table 4 Categories for different challenges experienced when engaging with SoTL (Adendorff, 2011)

| NP | Negative perceptions of SoTL: lack of academic rigour (easy, low-hanging fruit), inferior status of SoTL vs disciplinary research |
| RR | Recognition & Reward: limitations for career progression, institutional devaluing of SoTL vs disciplinary research, diverting focus and time from disciplinary research |
| DM | Nature of SoTL Research: mastering new discourse and methodologies, lack of theoretical perspective (inexperience) |
| TI/DI/RI | Identity: confusion of identity as SoTL vs disciplinary researcher, marginalisation within opposing communities of practice, recognition of researcher status, credibility & competency as researcher |

Results and discussion

Most participants reported that a love of teaching was the reason, or one of the reasons for choosing an academic career. In the cases where teaching was not an explicit motivator, they reported that they quickly came to love teaching and engaging with students. As such, the group identified strongly with their teaching role.

There was general consensus that, as a teacher, reflecting on your practice is important and that it directly influences student learning. What is happening in your classroom, who your students are, and how they learn matters. Participants felt that being a reflective practitioner with respect to one’s teaching should be a requirement, part of the core academic role, but participants also noted that it is not promoted as something that is critical or a priority for SU. There is no penalty for not critically engaging with or reflecting on one’s teaching.

So, at the first level, the facts of being a reflective practitioner, I think that’s really valuable and that’s something that we’re really not – that hasn’t been practiced throughout the faculty as far as I see.

I think every lecturer, if they have a passion for students and they want to do their job properly, would engage with this naturally. But we know that that doesn’t happen. So now you have to manage people to do it.

Reviewing SoTL literature was seen as a valuable activity, but primarily for developing one’s teaching practice in order to promote student learning, rather than for developing one’s SoTL research competency. Participants found that reading about how students learn, exploring different pedagogical approaches, and exposing oneself to different ideas for explaining concepts, designing classroom activities, and setting up effective and efficient assessments provided an invaluable resource in supporting their teaching role.
I need to know what is in the literature, I need to know the terms, I need to know the theories. And those theories were luckily very, very useful to me, which (they) should be. I mean, the Scholarship of Teaching and Learning theory should be useful and it was really practical.

A few lecturers made direct connections between teaching in order to prepare engineers for industry, while others spoke about SoTL as separate from and not related to their disciplinary research. One lecturer highlighted the link between disciplinary and SoTL research:

I see my personal research as a vehicle for training post graduate students. And those students might go into research institutes or private companies and do research there or they might become academics themselves. But I need to equip them so that they can become excellent researchers. So I must engage with scientific research to think that I can train students up to be good researchers for themselves. In the same way. I need to engage with the Scholarship of Teaching and Learning so that I can provide the teaching and learning that my undergraduate students require.

The formal T&L training provided in the professional development for new academic staff programme (PREDAC) was clearly highlighted as a critical influence in initiating and promoting a scholarly approach to teaching. It provided focused time and access to expert support for induction into a completely new research area and discourse.

I think the fact that I'm a very new lecturer and the PREDAC course gives a very good entry into that. So I had no idea that that (SOTL) even existed. You know, as an engineer you talk to engineers, you go out and work in the field as an engineer and then you come back here and go into a classroom of a hundred students, you know it’s ‘teach’.

Access to and the support of an expert T&L team facilitated quick adoption of new theories and concepts; this was also seen as a critical initiative in supporting the development of one’s teaching practice. The threshold level for understanding SoTL discourse and theories that is required in order to participate in an effective and scholarly manner, in designing and evaluating theoretically grounded interventions and investigations, is viewed as too high to be feasible without the support of a T&L expert.

It’s (T&L theory) something that is very new to me. I've actually only been exposed to it within the past two years. It was a completely foreign, completely foreign idea to me. And it was literally very foreign. I didn't even know what that word ‘pedagogy’ means. And a lot of the words that are in this space – I am still trying to navigate around them.

And I was ready to kind of abandon these things, but then I met (T&L expert), and I decided, okay, I'll just go along with your enthusiasm and you can bring the big scholarly words into our publications, so there’s a bit less pressure on that.

Participants recognise that there is a baseline quality of research that is required in order to contribute to their field of engineering research. They find it difficult to legitimise moving into the field of SoTL research without the same level of fundamental knowledge and expertise that they expect from published researchers in their own disciplinary research. They are able to rationalise this transition by collaborating with an expert in educational research on whom they rely to provide the academic and scientific rigour that they feel ethically bound to uphold.

But I think we're fooling ourselves when we say that, as an engineer, I’m equipped to really be easily engaged in a completely different research field, right?…obviously people are talking about that (being a teaching scholar) being a valid option, but then, you know, that should be performed at the same quality as what we expect from technical research. And then (it) should be recognised that that's the difficult part. I mean I could equally well start to decide, you know, I want to start contributing in quantum physics, all right? It’s a different field.

There is definite consensus that there is institutional recognition and reward offered for professionalising one's teaching practice by progressing from “reflective practitioner” to “teaching scholar”; however, the perception is that there a noticeable omission of recognition or reward offered at the intermediary “scholarly teacher” category. Participants noted that it is
necessary to participate at the teaching scholar level in order to for their work to be recognised at an institutional level. However, it is not seen as a critical activity and the return on investment is low.

So, I mean this idea is a little bit philosophical, but whenever you prioritise something else above yourself then you’re not going to get as much as you do when you prioritise yourself first. So if I go out, I can go out with the authority of getting the best possible mark for my performance evaluation, and?... no impact, you know, on what I do. Or I could go out with the perspective of doing the best that’s possible for my students and at times that’s going to not be recognised on the performance evaluation.

So the question that comes to my mind is, Why do they want to do that (promote SoTL at SU)? Because, you know, I mean, the university is a research-intensive university and we’re very good at that, you know. Hence the drive towards the publications and all that kind of stuff. So for them to say that that’s what they’re going to do then I think the university has to then change the drive. And if they want to support that, I think actually then rather than support it, they should then make that a priority, they should make it one of the priorities. And then everything else needs to fall in line and reflect that it is a priority rather than to support because supporting means… there’s an option.

The only tangible value for participating at a scholarly teaching level was to promote student learning, and this value is realised primarily in the personal reward associated with the satisfaction of feeling like the effort makes a difference to students.

I think that without things like PREDAC, which really brought this perspective into my life, I would be at the level, at this point that I was second semester, two years ago. And two years, two cohorts of students would have suffered under my teaching. And I think that that’s something that’s important. I think, T&L is difficult to quantify but I think its absence will be obvious, I think so.

The most significant investment required for participating in SoTL research is time, and that is an academic's most valuable resource. Participants are extremely aware that they continually have to evaluate and prioritise activities and their time, and as engineers they approach the problem in a systematic and logical manner. If an academic's purpose is to garner recognition and respect as an expert and researcher, pursuing SoTL is seen as an ineffective path in doing so. Disciplinary research pays a far higher dividend for the investment, both institutionally and personally.

I've got no interest in having an international SOTL network. So I don't think I'll ever be an internationally recognised researcher in SOTL.

It's probably because it's not engineering. You know engineers like to be engineers. So even me, I like to do what engineers do.

Why would I do that? So honestly, you tell me, why would I do that, why? Do I want to become a better scholar? No, I’m never going to be there. I’m not going to become an international… I’m researching in my field and publishing in my journals where I know we walk the field and so on. So I'm not going to be a researcher into education. I’m doing this so I can just, sort of, manage my class better and save myself time.

To summarise, engineering academics had a good understanding of the different levels of SoTL engagement, as defined by Trigwell's model in Table 3. However, while the first four levels (SOTL.A-D) were viewed as activities that were interesting, and valuable for improved student learning and teaching proficiency, the institutional recognition and reward is marginal and not worthwhile. These first four levels align with the “scholarly teacher” category from Table 1. Academics perceive that in order to receive reward for their SoTL engagement at these levels, they need to move swiftly into the “teaching scholar” category from Table 1, which aligns with the fifth level (SOTLE) from Table 3. The fast-tracked progression to the “teaching scholar” category is enabled by the support of academic development initiatives, such as the PREDAC programme and the expert T&L support staff. Even so, academics do not feel that
there is sufficient motivation for diverting time and resources from their disciplinary research areas in order to develop their T&L researcher identity. Their career development and promotion is better serviced by focusing their resources on their disciplinary research. This is a view that is typically promoted by their more experienced and senior colleagues. SoTL is seen as a "nice to have" and not as a necessity or priority. These perspectives align with some of the challenges identified by Adendorff as presented in Table 4.

Conclusions

The study shows that academics in SU Faculty of Engineering identify with their teaching role and see this as a core activity. They agree that reflection on teaching practice should be the baseline expectation from all academics, and that progressing to the "scholarly teacher" level is beneficial for developing one's teaching practice and improving student learning. However, this is not viewed as critical or a priority for one's career advancement. Most participants were only motivated to engage in higher levels of SoTL due to the support of T&L experts and formal training opportunities.

The recognition and reward offered by SU to incentivise the professionalisation of an academic's teaching practice is seen as marginal, and only realised when the "teaching scholar" level is reached. Therefore, academics are not significantly motivated to continue developing their teaching practice beyond the initial prescribed T&L training programmes, such as PREDAC. Participants identify more strongly with their disciplinary research. Investing time and energy on their disciplinary research is seen as more beneficial for their career development and promotion than pursuing the professionalisation of their teaching role.

Participants noted that if SU wishes to promote the professionalisation of teaching, and expects academics to progress along the levels of teaching practice as outlined in the T&L policy, then it needs to explicitly prioritise this as an academic imperative. This means that the very real gap, between the intent of the SU T&L Policy and how it is playing out in the teaching environment, would have to be bridged by ensuring that it is understood and implemented effectively at the departmental level. This would require revision of performance and promotion criteria, and strong leadership to get buy-in from all stakeholders.

References


Developing T-shaped individuals through the Master of Philosophy specialising in Sustainable Mineral Resource Development programme at the University of Cape Town

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Abstract: There is a need for robust, versatile and resilient professionals, who are capable of adapting to and working in a variety of technological, cultural and societal contexts. T-shaped professionals are embedded in one discipline or knowledge system and have broad-based skills and competencies which allow them to expand their understanding of and communication with other disciplines and stakeholders.

This paper investigates the contribution of student reflection on the extent to which a particular Master of Philosophy (MPhil) programme succeeds in developing T-shaped professionals, which is achieved through a questionnaire for participants supplemented by in-depth interviews with the participants and course developers.

To date, 92% of questionnaire respondents would consider themselves T-shaped individuals/professionals at the end of the first year of the MPhil specialising in Sustainable Mineral Resource Development (SMRD). An analysis of the research findings demonstrates differences in how students think, live and behave after their MPhil SMRD journeys and relates these differences to characteristics of T-shaped professionals. This is then used to assess the contribution of student reflection on their personal journey towards becoming T-shaped professionals.

Introduction

Current global problems are recognised as interconnected and complex. They can no longer be solved by one nation, by one discipline or in isolation. Complex problems have caused industries to change the way it perceives and responds to global and societal challenges, particularly those challenges pertaining to sustainable development. For instance, the mining and primary minerals sector needs to deal with the implications of increased production costs and volatile metal markets in the face of growing legislative and socio-political pressures that threaten both the industry’s financial viability and its licence to operate.

Complex problems have given rise to the number of pluri-disciplinary teams, who seek to solve or ameliorate the impacts of global problems. Pluri-disciplinary teams are teams consisting of members from multiple disciplines. In order to produce innovative and frame-
changing solutions through effective collaboration, the members of pluri-disciplinary teams would need to overcome barriers embedded in each team member’s mono-discipline whether it be jargon, disciplinary culture or the method of sharing knowledge (C. Z. Miller, 2016).

The development and formation of pluri-disciplinary teams, as well as global and societal challenges resulting from complex problems, are shaping a different perspective on what characteristics professionals ought to possess. According to the World Economic Forum’s (2016) “Future of Jobs” report, the top ten skills needed by employers by 2020 are complex problem solving; critical thinking; creativity; people management; coordinating with others; emotional intelligence; judgment and decision-making; service orientation; negotiation; and cognitive flexibility. Hence, graduates require more than just deep disciplinary knowledge in one specialism. They require a well-rounded set of interpersonal skills which allows them to operate independently as well as in a team. There is a growing need for robust, versatile and resilient professionals who are capable of adapting to working in a variety of technological, cultural and societal contexts. These individuals are known as T-shaped individuals.

A T-shaped individual is an individual embedded in one-discipline or knowledge system (i.e. their depth) who also have broad-based skills and competencies that allow them to expand their understanding of and communication with other disciplines and stakeholders (i.e. their breadth) (Brown, 2009, 2010; Hansen & von Oetinger, 2001; The University of Cambridge IfM & IBM, 2008) – illustrated in Figure 1. These individuals are capable of combining several forms of knowledge whether it be theoretical knowledge from multiple disciplines or experiential knowledge from lived experiences. The combination of knowledge banks often results in the creation of new knowledge and the expansion of their knowledge base and skillset (Madhavan & Grover, 1998). These individuals also develop an awareness of the potential impacts of their tasks or actions in different environments or contexts (Iansiti, 1993). Hence, T-shaped individuals are valuable assets in pluri-disciplinary teams because of their roles in knowledge creation, innovation and networking (Boynton, 2011; Leonard-Barton, 1995).

Figure 1: A detailed diagram of a T-shaped individual. Source: “T-Academy 2017”

It is not explicitly stated which skills classify an individual as a T-shaped individual but many studies (Brown, 2009, 2010; Civil Service College, 2014; Hansen & von Oetinger, 2001; N. Miller, 2016; R. K. Miller, 2015) identify attributes and skills which they possess. These attributes and skills are compiled in Table 1 below. It must be emphasised that these individuals possess these ‘soft skills’ because creative problem-solving activities require balancing the specialised knowledge with skills used during knowledge integration and application, i.e. balancing their depth and their breadth.
**Table 1: A summary of the attributes and skills need to become T-shaped individuals in the context of the extractive industry.**

<table>
<thead>
<tr>
<th>Attributes and skills</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Critical thinking required to understand the broader context and impacts of one’s</td>
<td>(Hansen &amp; von Oetinger, 2001; N. Miller, 2016)</td>
</tr>
<tr>
<td>specialised skillset</td>
<td></td>
</tr>
<tr>
<td>Listening and communication skills (verbal and written) used to comprehend another’s</td>
<td>(Hansen &amp; von Oetinger, 2001; Brown, 2009, 2010; Lee, 2011)</td>
</tr>
<tr>
<td>specialised skills and knowledge, as well as to market one’s specialised skills</td>
<td></td>
</tr>
<tr>
<td>Tolerance and open-mindedness</td>
<td>(Leonard-Barton, 1995; von der Heyde, 2014)</td>
</tr>
<tr>
<td>Enthusiasm and willingness to learn</td>
<td>(Hansen &amp; von Oetinger, 2001; M. Lee, 2011; Leonard-Barton, 1995)</td>
</tr>
<tr>
<td>Gain and improve knowledge of how humans and society work</td>
<td>(M. Lee, 2011; Y.-C. Lee &amp; Lee, 2007)</td>
</tr>
<tr>
<td>Ability to work in a team</td>
<td>(The University of Cambridge IfM &amp; IBM, 2008; Kos, 2017)</td>
</tr>
<tr>
<td>Networking</td>
<td>(Kos, 2017; Kouchaki, Gino, &amp; Kouchaki, 2016; Rodale, 2016)</td>
</tr>
<tr>
<td>Understand the industry that one is working in, such as the current affairs, the</td>
<td>(H. Lee &amp; Choi, 2003; Madhavan &amp; Grover, 1998; R. K. Miller, 2015)</td>
</tr>
<tr>
<td>trends and the recent innovations</td>
<td></td>
</tr>
<tr>
<td>Understand how the business world and how the extractive industry works and fits</td>
<td>(Kos, 2017)</td>
</tr>
<tr>
<td>together</td>
<td></td>
</tr>
<tr>
<td>Time management</td>
<td>(Iansiti, 1993; Madhavan &amp; Grover, 1998)</td>
</tr>
<tr>
<td>Creativity and innovation</td>
<td>(Brown, 2010; Sunthonkanokpong, 2011)</td>
</tr>
<tr>
<td>Leadership and organisation</td>
<td>(Mbabane, 2008)</td>
</tr>
</tbody>
</table>

**Background to the Master of Philosophy programme specialising in Sustainable Resource Development**

The challenges and changes in the mining industry, such as the complex inter-relations with local communities and the operationalisation of the Sustainable Development Goals, make extensive research in human capacity development within the context of the extraction and processing of mineral resources of paramount importance. Deloitte's 2013 'Tracking the Trends' report observed a skills shortage in the mining industry which threatened the long-term viability of future mining projects. This skills shortage is again addressed in Deloitte's 2018 'Tracking the Trends' report where a new type of individual is required to adapt to the dynamic nature of the mining industry. These individuals require a dynamic, interdisciplinary environment to flourish (Broadhurst, Harrison, Petersen, Franzidis, & Bradshaw, 2016).
The Master of Philosophy programme specialising in Sustainable Mineral Resource Development (MPhil SMRD) is coordinated by the Department of Chemical Engineering at the University of Cape Town (UCT). It is a two-year long degree programme that was developed as part of the Education for Sustainable Development in Africa project initiated by the United Nations University Institute for Sustainability and Peace. The MPhil SMRD is offered and delivered collaboratively by UCT and the University of Zambia. It aims to highlight “the critical factors of sustainable development in the context of mining and minerals processing in Africa”, which includes “an understanding of, and a sensitivity and progressive approach to, managing and interacting with communities, environmental challenges, safety cultures, health-related issues and regulatory frameworks” (UCT EBE, 2017: 1). Selection of the MPhil SMRD candidates is based on the applicant’s academic record as well as their duration, level and relevance of any work experience. The MPhil SMRD is open to graduates from various disciplines such as engineers, geologists, lawyers, economists and social scientists. Students are selected based on their disciplinary background and work experience to diversify the cohort and student experiences.

The MPhil SMRD comprises 60 credits of coursework, which are divided into four core courses offered by different universities (outlined in Table 2), and a 120-credit research dissertation, which is written in the second year of the MPhil SMRD and interdisciplinary research and partnerships are promoted and encouraged. The MPhil SMRD also includes a mandatory internship with a sustainability expert or practitioner which should be completed any time during the two-year programme.

Table 2: A summary of the courses in the MPhil SMRD Source: UCT EBE (2017).

<table>
<thead>
<tr>
<th>Course Description</th>
<th>Convening Institute</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sustainable Development</td>
<td>Stellenbosch University (in collaboration with the Lynedoch Sustainability Institute)</td>
<td>16</td>
</tr>
<tr>
<td>Strategic Social Engagement Practice</td>
<td>Graduate School of Business, University of Cape Town</td>
<td>16</td>
</tr>
<tr>
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Methodology

The purpose of this study was to understand the experiences of students and course developers participating in the MPhil SMRD and to determine the types of skills and attributes that were being developed or enhanced. Drawing from the themes and concepts of phenomenography and participatory research, this study adopted a qualitative and quantitative methodology by using in-depth interviews with the MPhil SMRD students and course developers, and a questionnaire filled in by MPhil SMRD students. The interviews and the questionnaire were conducted in 2018. After the receipt of ethical clearance, an e-mail invitation for both the interviews and questionnaire was sent to the 2014, 2015, 2016 and 2017 MPhil SMRD cohorts using the e-mail addresses from university records.

The questionnaire was designed and analysed using Jama, Mapesela, & Beylefeld’s (2008) circles of progression model, and was completed online by all respondents. In this paper, all questionnaire data will be presented and discussed.
The interviews were conducted face-to-face and audio-taped for transcription. The interviews were guided by a semi-structured protocol where all participants were encouraged to share their narrative in detail such as any outstanding stories, lessons learnt, opinions or personal reflections during their participation in the MPhil SMRD. The transcriptions were analysed following Polkinghorne’s (1995) concept of narrative analysis, where each transcript was considered and explored individually before being analysed as a whole. In this paper, only two interviews will be discussed.

Results

Questioning the MPhil SMRD students

In 2018, approximately 53 MPhil SMRD students were contacted for the questionnaire. 12 participants completed the questionnaire; of which, five respondents (41.7%) were from the 2015 cohort and seven respondents (58.3%) were from the 2017 cohort. Of the 12 respondents, three respondents (25%) had already graduated.

Basic descriptive statistics were performed on the questionnaire data. It was found that 67% of the questionnaire participants were male and 33% were female. With regards to age, 50% of the participants were in between 20 and 29 years old, 33% were between 30 to 39 years old and the remaining 17% between 40 to 49 years old. With regards to nationality, 83.3% of the participants originate from an African country with the remaining 16.7% equally distributed between those originating from Australia and Japan. Figure 2 illustrates the distribution of the first degrees of the questionnaire participants. Moreover, 33% of the respondents are full-time students and the remainder are full-time employees.

Figure 2: Distribution of the first degrees of the questionnaire participants.

The questionnaire participants were asked to describe themselves as students before beginning the MPhil SMRD. The most commonly used descriptor was “naïve”. Other notable descriptions included “eagerness to learn”, “unilateral” and “seeking self”.

The questionnaire participants were then asked to describe their overall journey through the MPhil SMRD. The most commonly used words were “interesting” and “challenging”. Other notable descriptions included “transformational”, “life-changing”, “mind-shift”, “reflective” and “thought-provoking”.

Using the definition of a T-shaped individual stated above, the questionnaire participants were asked twice whether they would describe themselves as a TI: scenario one, before entering the MPhil SMRD and scenario two, after the MPhil SMRD.
In the first scenario; 6 of the participants (50%) responded ‘no’, 5 of the participants (42%) responded ‘somewhat’ and the remaining participant (8%) responded ‘yes’. The questionnaire participant, who described themselves as T-shaped before entering the MPhil SMRD, said that they already had a broad range of experience and knowledge of the mining industry and its infrastructure with enough disciplinary knowledge and background on sustainability to be considered a TI before the MPhil SMRD.

In the second scenario; 11 of the participants (92%) responded ‘yes’ and one participant (8%) responded ‘no’. One questionnaire participant, who changed their description of themselves as a TI, said that they “learnt to incorporate divergent views, developed a willingness to learn and analyse how different systems in life interact with each other”. This aligns with sentiments expressed by two other participants: one participant believed that they are “able to comfortably and effectively interact with other individuals from different backgrounds, cultures and academic levels” and another stated that they are “able to articulate issues using different lenses”. One participant stated that the MPhil SMRD equipped them with skills to remain open to an understanding during collaborations in order to achieve goals more effectively. On the other hand, the one questionnaire participant, who would not describe themselves as T-shaped both before and after the MPhil SMRD, said that, although the MPhil SMRD provided them with the space to become a TI, they would not consider themselves as an ‘official or developed T-shaped individual’. This participant described themselves as a “developing T-shaped individual” because of their lack of experience outside of the university or in a variety of societal contexts or work environments.

The questionnaire participants were then asked to state which skills and attributes they acquired or enhanced during their MPhil SMRD journey (see Table 1). The top three skills, with a 100% response, were ‘critical thinking’, ‘listening and communication skills’, and ‘tolerance and open-mindedness’. There was a 92% response on ‘enthusiasm and willingness to learn’; an 83% response on ‘gain and improve knowledge of how humans and society work’, ‘ability to work in a team’ and ‘networking’; a 75% response on ‘understand the industry that one is working in, such as the current affairs, the trends and the recent innovations’ and ‘understand how the business world and how the extractive industry works and fits together’; and a 67% on ‘time management’ and ‘creativity and innovation’. The lowest response was 50% on ‘leadership and organisation’.

The questionnaire went further to distinguish a T-shaped individual and a T-shaped professional. In this study, a T-shaped professional is an individual who has (1) specialised in discretionary knowledge, skills and qualifications, (2) works in an occupation that has achieved the status of ‘profession’ in a recognised economy’s labour force, (3) adheres to the code of conduct of their profession, and (4) exhibits the sense of decorum integrity, trustworthiness and what is considered professionalism by their profession.

When the questionnaire participants were asked if they would describe themselves as T-shaped professional, 8 of the questionnaire participants (67%) responded with ‘yes’ and the remaining 4 questionnaire participants (33%) responded with ‘no’. All the questionnaire participants, who described themselves as T-shaped professionals, substantiated their responses with how they apply their new skills currently and attributes in their professional contexts. All but one of the questionnaire participants, who do not describe themselves as T-shaped professionals, were young full-time students. This is a shortcoming of this study considering that more than 60% of the MPhil SMRD participants over the last five years have not been full-time students, but employed. The full-time students reasoned that, even though they act in a professional capacity and have set themselves up to be T-shaped individuals, they do not have enough work experience or professional experience to describe themselves as T-shaped professionals. Interestingly, one of the questionnaire participants, who would not describe themselves as a T-shaped professional, was a manager. They reasoned that, even though the MPhil SMRD provided the building blocks that triggered the development of their T-shape, they considered themselves as an individual who was “transitioning into a T-shaped professional”.

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Interviews: the experienced engineer and the young engineer

One MPhil SMRD course developer and one MPhil SMRD student were interviewed: Mary and Patricia, respectively. Mary was one of the main contributors to the development and design of the MPhil SMRD because of her experience as a mining engineer and an academic. Mary remains an active member of the MPhil SMRD educational staff. Patricia is a fresh, young chemical engineering graduate with an immense passion for people and their stories. She applied for the MPhil SMRD hoping to bridge the gap between engineering and people.

Perspectives on the MPhil SMRD

Mary attested to the personal and professional transformations experienced by MPhil SMRD students and graduates underwent during their participation in the MPhil SMRD programme; whereby some students went on to change the way they do business, whilst others drastically changed their personal lifestyles. Patricia affirmed that the MPhil SMRD provided her with the opportunity to develop her interpersonal skills by creating uncomfortable spaces to work in. Patricia concluded that the MPhil SMRD has made her a more empathetic, a better listener; improved her understanding of the role she plays in society and the economy; made her a more assertive as a leader; improved her networking skills; and provided her with a space and tools to become more self-aware of her strengths and shortcomings.

Mary believes that the transdisciplinarity of the MPhil SMRD’s learning and teaching space produces individuals who are capable of overcoming disciplinary barriers. Mary said that the diversity, i.e. the differences in age, gender, disciplines and work experiences, within the MPhil SMRD classroom develops skills, and fosters conversations and partnerships needed for effective and successful collaborations. Patricia corroborated that her classmates, who specialise in different disciplines and have worked in different sectors in the extractive industry, enhanced and broadened her perspective of the mining industry, sustainability and the world. Patricia observed that the class formed a sense of unity and common values during the year.

Perspectives on T-shaped individuals

The MPhil SMRD UCT development team adopted Tim Brown’s term of a T-shaped individual. This term was chosen because it “fitted the bill”. According to Mary, the MPhil SMRD UCT development team translated the breadth of the ‘T’ to include a broader understanding of the sustainability challenges facing the minerals sector and the environment and society in which it operates, as well as an ability to relate this understanding in the context of different stakeholders and disciplines. In this context, Mary believes that the MPhil SMRD may be creating a more evolved version of the TI compared to the original definition describe by Brown.

Based on the definition given by the research team, Patricia considered herself a ‘developing TI’ because she is still “building her breadth”, i.e. her boundary-crossing competencies. She recognised the limitations of her newly enhanced and developed skills and acknowledges that she is still disseminating and learning to understand different types of knowledge as well as learning how to integrate the acquired knowledge. However, Patricia would not go as far as to consider herself a T-shaped professional because she believes being a professional depicts a one-dimensional aspect of an individual’s professional capacity. Rather, she presents herself as a critical thinker who is capable of adapting to and participating in various environments and contexts.

Thoughts on the MPhil SMRD

Patricia cautioned people who are thinking about participating in the MPhil SMRD because she believes that students would need to be open-minded and emotionally prepared for the “very intense” learning and teaching space of the MPhil SMRD. On the other hand, she
encourages people, who aspire to be senior managers and leaders, to consider the MPhil SMRD for postgraduate education.

Interestingly, Mary agrees that an individual would need to be open to some type of transformation when participating in the MPhil SMRD, especially when dealing with transdisciplinarity. She also advises her students to consider the career they intend to follow before applying for the MPhil SMRD because some careers find it difficult to recognise the value of the MPhil SMRD. She explained that although more progressive careers, such as management consulting, prefer degrees that develop interdisciplinary mindsets and offering experience working in pluri-disciplinary teams, other more traditional careers in the mining industry still prefer traditional disciplinary mindsets and degrees.

Discussion

The evidence suggests the MPhil SMRD is providing the space for the development of T-shaped individuals. All of MPhil SMRD participants changed their perception of themselves as T-shaped during their participation of the MPhil SMRD, with the exception of one MPhil SMRD participant who already considered themselves a T-shaped individual before entering the programme. This change is apparent in the questionnaire data. Moreover, this change in perception appears to occur during the first year of the MPhil SMRD when participants attend lectures and complete assignments because only three of the questionnaire respondents graduated.

The MPhil SMRD develops and enhances an array of adaptable skills, personal attributes and resilience – listed in Table 1. When comparing the skills developed or enhanced during the MPhil SMRD and the top ten skills listed in World Economic Forum’s (2016) “Future of Jobs” report, there is a distinct association whereby critical thinking, self-awareness, teamwork and communication are valued. This is further corroborated by Patricia in her interview.

The MPhil SMRD may also be developing T-shaped professionals. It must be reiterated that the majority of the questionnaire respondents, who consider themselves T-shaped professionals after the MPhil SMRD, are full-time employees. The questionnaire respondents, who do not consider themselves T-shaped professionals, mostly consisted of full-time students with no professional experience. Interestingly, Patricia elaborated that she would not consider herself a professional but rather a critical thinker because it provided a more holistic depiction of what she had to offer professionally.

The pluri-disciplinary nature of the learning and teaching space played a significant role in the creation of T-shaped individuals. It also alludes to the assumption that the diversity in gender, age, disciplinary knowledge and occupations of the MPhil SMRD influences student experiences during the MPhil SMRD and what they gain from their experience. In Patricia’s case, she recounted that her experience and perspective of the mining industry and sustainability were enhanced because of the diversity of her classmates’ knowledge and experiences. The two questionnaire respondents, who were quoted above, also ascribe their skills development to working in teams and participating group discussions.

Moreover, it takes certain attributes to successfully persist during the MPhil SMRD because of the personal transformations that MPhil SMRD participants undergo. Patricia described the learning and teaching space as “very intense”. She also cautioned those who are considering participating in the MPhil SMRD because of the emotional investment. Both Mary and Patricia recommended tolerance, open-mindedness and enthusiasm as the required qualities an individual who is entering the MPhil SMRD’s learning and teaching space. Contrasting the latter, a few questionnaire respondents described themselves as “close-minded” and “naïve” at the beginning of the MPhil SMRD. This could be an indication of how the MPhil SMRD has transformed the thinking of the MPhil SMRD participants. However, these descriptions are retrospective reflections and could attest to the personal transformations that MPhil SMRD participants have already undergone. Further investigation
is needed to understand whether the MPhil SMRD participants are pre-dispositioned to be T-shaped considering their personal attributes.

**Conclusion**

This study demonstrates how the participants of the MPhil SMRD develop their identity as T-shaped individuals during their time in the MPhil SMRD programme. It documents a student account of the development of adaptable skills and attributes needed to solve or ameliorate the dynamic complex problems the world is currently facing. Whether the MPhil SMRD is developing these 'T-shaped skills' efficiently remains to be investigated.

Considering the accounts and recommendations of the two interviewees, the MPhil SMRD has the potential to contribute to the development of T-shaped professionals who play a constructive and key role in the sustainable development and management of Africa's mineral resources. Further critical engagement with the participants of the MPhil SMRD could provide unique insights into the requirements for developing and promoting a new trans-disciplinary pedagogy in the higher education sector within the context of the sustainable development of mineral resources.

**References**


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Volume II: Extended abstracts
Authentic Assessment in Engineering Education: a systematic literature review

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Despite a major discussion on the implementation of authentic assessment in engineering faculty through the 2000s, little progress appears to have been made towards widespread adoption in engineering education. This paper explores a systematic literature review on authentic assessment applied in a real-world and meaningful context for the future engineer’s graduates. Authentic assessment in the field such as medicine, business and education are widely used to assess students based on activities that replicate real-world performances as close as possible, following that previous study in engineering education indicated the contrary. The rationale for the examination stems from the notion that there has been an increasing interest in the engineering education research community in What theoretical framework and perspectives have been applied to authentic assessment in engineering education?

Keywords: Authentic Assessment, Performance-based assessment, Engineering Education.

Introduction

Based on results of the global skills survey across 42 countries, including South Africa, reveals that one of the key reason for being unable to appoint graduates their perceived lack of required technical skills (Wolff, 2018:1). Sound knowledge of engineering theory and practice alone is no longer sufficient to meet the demands of the market place. Realising that assessment frames learning and often effect learning more than teaching, the literature review on authentic assessment in engineering education showed the need for developing an authentic assessment strategy in engineering education for all subjects.

According to Wiggins (1989), Herrington (2010), Shay (2010) and Boud (2000,2010), authentic assessment requires that assessment practices promote the practice of directly assessing students on credible intellectual tasks, as opposed to making inferences about students’ abilities through indirect assessment. Authentic assessment tasks help students to focus on demonstrating their ability to discern critical knowledge and to act effectively in situations that make sense in their future professional contexts. Recent years, authentic assessment has been developed and evaluated for other faculties but no rigorously tested for engineering disciplines. This paper will observe how an authentic assessment has been implemented in the engineering faculty.

The objective of this paper is to (1) demonstrate how an authentic assessment can address the real-world application into the assessment curriculum, (2) describe how the effectiveness of authentic assessment will be determined, (3) share results on the impact authentic assessment on student learning.

The methodology of the systematic review of authentic assessment

For this paper, we used a framework for the literature review developed by Borrego et.al. 2014. This paper describes a systematic literature review as the methodology of authentic assessment to promote the development of an authentic assessment in the engineering...
education field. A systematic review of authentic assessment was carried out with the purpose of integrating, analysing and identifying central themes. I analysed 120 articles, book chapters and conference proceedings that focused on the subjects and were published between 2000 and 2019. All items in the data – based were read and articles that were not relevant to the topic, or that were ‘opinion research’ rather than empirical research, or very short papers (shorter than 2 pages) were excluded, resulting in final data – based of 63 papers of studies. Table 1 provides a schematic representation of the search strategy.

Table 4: Schematic search strategy

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<th>Search items</th>
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<td>Higher Education Research &amp; Development Education</td>
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<td>Education for Chemical Engineers</td>
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<td>“Authentic assessment in engineering education” OR “performance-based assessment in engineering education” OR “work-integrated learning WIL in engineering education” OR “problem –based learning (PBL) assessment in engineering education” OR “sustainability in engineering education” AND “wicked assessment in engineering education” OR ill-structured problems”</td>
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**Authentic assessment in engineering education**

Wiggins (1989), who first related the term ‘authentic assessment’ to student assessments in 1989, defined ‘tasks set in a real-world context’ as tasks which ‘are either replicas of or analogous to the kinds of problems faced by adult citizens and consumers or professionals in the field.’ As opposed to authentic assessments, traditional assessments are largely
decontextualised in nature, not allowing students to relate classroom learning to workplace situations. The study has been conducted by Prasetyo (2017) in relation to authentic assessment compared to traditional assessment. A study completed by Ghosh (2017) found the important aspect that authentic assessment collects the evidence of the students' competence to perform workplace tasks. Prasetyo listed six elements with differentiating a traditional test from an authentic assessment as follow in Table 1.

Table 1: Comprising studies between traditional assessment and authentic assessment (Prasetyo, 2017).

<table>
<thead>
<tr>
<th>No</th>
<th>An aspect of the study</th>
<th>Traditional assessment – assessment of learning</th>
<th>Authentic assessment – assessment for learning and as learning</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>Students’ preparation</td>
<td>Knowing in advance to ensure the validity</td>
<td>Most of the cases it is not announced before</td>
</tr>
<tr>
<td>2</td>
<td>Focus</td>
<td>Students’ performance</td>
<td>Students' progress, students engagement, validate and reliable performance</td>
</tr>
<tr>
<td>3</td>
<td>Results</td>
<td>Score / grade</td>
<td>Marking according to the rubric. Extended feedback (Mark 1, 2) and monitoring progress.</td>
</tr>
<tr>
<td>4</td>
<td>Frequency</td>
<td>Regularly planned as a form of formative and summative assessments</td>
<td>Continuous during the year. Demonstration (report, critique, and feedback).</td>
</tr>
<tr>
<td>5</td>
<td>Format</td>
<td>Oral presentations, multiple choice questions tests, written exams based on the covered material.</td>
<td>An integrated project, portfolio, logbook, case studies (problem-based tests), wicked problems, practical skills tests (formative feedback)</td>
</tr>
<tr>
<td>6</td>
<td>Context</td>
<td>Frequently contextualised</td>
<td>Contextually simplified engineering problems and design solution. Disciplinary content in more applied ways</td>
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</table>

The study found by Wiggins also gives a comparison between authentic assessments and typical tests. Wiggins stated if the assessment is truly authentic, the kinds of skills it invokes would have been practiced many times before in a wide range of situations so that they become predictable as indicators for learning. Wiggins mentioned that typical tests have only correct answers whereas authentic tests are iterative, “containing recurring essential tasks”. Traditional tests are more summative in nature, but authentic tests provide diagnostic information and feedback to the student so that they can see where and how to make a correction (Wiggins, 1998). Furthermore, Boud (2010:15) also mentioned that the notion of sustainable assessment built on a strong foundation of formative assessment that included the important move from the assessment of learning to assessment for learning.

This research started by noting a growing concern with an authentic assessment in engineering education. The authentic assessment may be a promising role for students' needs for improving students’ performance as well as student employability.
Making assessment completely authentic is a challenging process observed by many researchers in engineering education and will occur without educational leadership and support from lecturing staff. Engineering educators have a responsibility and opportunity not only to develop students' engineering science knowledge and skills but also sociotechnical and attitudinal competencies that required in the engineering field. One of the observations suggests creating a highly authentic task in education in a virtual setting possible be the will be a future step in only for work—integrated learning but also for assessing engineering at technical universities in South Africa.

Conclusion

Based on a literature review on authentic assessment, an authentic assessment goes together with sustainable feedback of the student progress. The notion of sustainable assessment: practices that meet immediate assessment needs whilst not compromising the knowledge, skills, and disposition required to support lifelong learning activities. The sustainable feedback supporting students to make their own professional judgments.

Understanding that the purpose of assessment is to improve student learning, many institutions earnestly work and have worked achieve that aim, directing the program to establish and follow a multi-semester assessment plan that explicitly plots when and how each of its learning outcomes will be assessed.

This paper is conceptual, systematic review and further empirical evidence is required towards the designing authentic assessment in engineering education by applying the pedagogical approach.

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References


Improving first-year engineering students experiences: the role of providing psychosocial support through life coaching

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Abstract
This study evaluated the use of small life coaching groups as a proactive means of providing psychosocial support to first-year chemical engineering students in an Extended Curriculum Programme. The proactive psychosocial intervention aims to harness students’ agency through life coaching so that they succeed in their studies and dropout rates reduced. Qualitative and quantitative data were collected through an evaluation form in which students reflected on their experiences of the psychosocial support. Results indicate that students reflected positively on their overall experience concerning their self-awareness, understanding their minds, knowing how their thoughts and feelings influence their behaviour and action, and how to deal with negative influences in their lives. As such, the psychosocial support intervention shows great potential in influencing students’ success and reduce drop out rates through harnessing their agency.

Keywords: Psychosocial support, dropout, engineering students, life coaching

Context
The dropout rate of students across higher education institutions in South Africa remains alarmingly high, with the current rate being greater than 40 percent (CHE, 2016). Notably, students who enter first-year engineering programs are some of the most sought-after in their cohort, and it remains a concern when these ‘cream of the crop’ students drop out. Current research in the South African Higher Education landscape indicates that the success of students entering engineering programs in the first year is influenced by both the knowledge gaps between high school and university, and by psychosocial reasons (Basitere & Ivala, 2015, Petersen et al., 2009). Much of the research in this area has primarily focused on correcting the knowledge gaps; however, there is recognition that, to improve student experiences and reduce dropout rates, issues of psychosocial support need to be addressed (Lekena & Bayaga, 2018; Bokana &Tewari, 2014).
Purpose
This study explored the use of small life coaching groups as a proactive means of providing psychosocial support to first-year chemical engineering students in an Extended Curriculum Programme (ECP). The greater need for proactive psychosocial support intervention comes in the recognition that much of the current drop out rates of first-year students in engineering is a result for psychosocial reasons. Thus the intervention aims to harness student agency for success through life coaching.

Methodology
Five small groups consisting of six to 12 students were coached for two full days (weekends) over five months. A total of 35 out of a cohort of 48 (73%) students participated in the coaching groups. After each coaching group, qualitative and quantitative data was gathered through an evaluation form that students were asked to complete. Students were asked to indicate on the form whether they give consent for their evaluation to be used for research purposes. All students in this cohort gave consent. Margaret Archer’s (1995, 2003, 2007, 2012) social theory concepts of human agency and reflexivity were used to interpret students’ reflections on their experiences of the intervention, and to better understanding its influence on their agency.

Theoretical framework
Archer’s morphogenetic social realist theory, rooted in critical realist philosophy of science, provides useful theoretical concepts to examine the interplay between the social structure (psychosocial support programme) and students’ agency. The purpose of the psychosocial support programme intervention, a social structure, was to harness students’ agency so that this, in turn, improves their experiences and academic performance. Archer (1995) refers to the structure as ‘the social relations between components of a social system that involves material resources’ (p. 180). Concerning agency, she refers to it as action by social agents. Following the critical realist notion of emergence, Archer’s theory proposes that both structure and agency have emergent properties, the structural emergent properties (SEPs) and the personal emergent properties (PEPs). SEPs condition the situations in which the agents find themselves and have to operate. While they pursue their self-defined personal projects, based on the things they care about the most (such as passing their courses) they mediate the conditioning effects of structure (such as the psychosocial support intervention they find themselves). They achieve this by excising their PEPs, whether individually through their ability to hold reflexive deliberations or collectively through collective action. The concept of reflexive deliberation (PEP), helps us understand the ways in which agents hold their internal conversations, and make decisions to act in particular ways, it helps us unpack how students mediated the SEPs of the psychosocial support intervention during the first year of their studies in engineering.

Results and Discussion
The results, summarised in figure 1, indicate that the provision of psychosocial support through the life coaching programme influenced students’ experiences of their first year positively. Students were able to understand how their minds work, how their thoughts and
feelings influence their actions, how to learn to let go of negative aspects of themselves, and how to improve their self-image.

Figure 1: A summary of students’ reflections of the psychosocial support intervention

Learning about all these aspects contribute to them realizing their personal power exercise their agency by holding positive reflexive deliberations, and exercising corporate agency was needed in the pursuit of their academic success. The work undertaken in this study contributes to seeking interventions that support students deal with psychosocial reasons noted by Basitere and Ivala (2015), and Lekena and Bayaga (2018).

Conclusion

The findings of this study indicate that the provision of psychosocial support through life coaching to first-year students in engineering has potential to play a significant role in improving their experiences of the first year, and hopefully ultimately reduce their dropout rates as well as encourage them to be well-rounded engineering graduates.
References


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The language question in Africa’s university engineering education: How optimal is multilingualism?

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Introduction
Following the 2015-2017 South African higher education students unrest, a Kanyarusoke and Ngonda (2017) study on decolonising engineering education at one South African University of Technology yielded four key areas to address. In order of importance as judged from students’ unprompted contributions, they were: curriculum in relation to Africa (72%), Race relations (70%), Facilities and Teaching (58%) and Language of instruction (21%). Following these findings, some changes in the authors’ teaching practices were introduced, and others already in place by then, strengthened. The approach was to tackle the most critical issues first, and in accordance with resources and means available or that could be most easily sourced. By the end of 2018, only the fourth point had not been attended to. This paper gives early efforts at addressing it.

Research Questions
Of concern was - first and foremost: In a decolonisation context further complicated by race relations, why did these engineering students not consider language as a bigger issue than they reported? Was this apparent anomaly particularly specific to the responding students or could it be symptomatic of a wider issue in engineering education? If Language is really an issue, what could be done about it in a multi-cultural class room with international students? If not such a strong issue, how should a normal lecturer act to get the few students thinking it to be an issue, move along with the rest without preventing the others from realising their full potential?

Methodology
Broadly, qualitative and quantitative methods were used to answer the above questions. On the first question, it was not possible to interrogate the particular respondents about it at this stage, since many ought to have left the university already. In any case, responses at the time of the earlier research were intended to be unprompted: hence, even then, it was – by design – not reasonable to probe the issue. Therefore, an approach involving engineering students not directly involved in the unrest and from a bigger sample on the continent was used to implicitly answer both this question and the second one.

Understanding that verbal language is basically one of four methods of engineering communication, we sought to test the relative importance of the four modes in enabling students understand engineering content. This would hopefully guide us on whether the students had not minded about ‘language’ because of other methods available to them. A list of four relatively simple engineering phenomena in civil, chemical, electrical and mechanical engineering was considered. The four methods of communicating each of these phenomena were randomly illustrated on a questionnaire, and the students were requested to voluntarily respond to each illustration on a 1-5 Linkert scale. This constituted the first 16 statements of the questionnaire. An in-built self-validating part was then added in form of 4 statements about the communication methods investigated by the 16 illustrations. The questionnaire was distributed to 9 universities, mainly through known engineering academic
contacts, on the continent as follows: three in Southern Africa, three in East Africa, two in Francophone Africa, and one in Anglophone West Africa. A copy of the questionnaire is available at Kanyarusoke’s Research gate page.

Responses on the returned questionnaires were quantitatively analysed at two levels. First, for each respondent and each engineering phenomenon, responses on each communication type illustration were synchronised, compared and ranked in order of student-perceived usefulness. This was then compared to responses in the self-validating part of statements 17–20. The second level of analysis was a statistical analysis of the global returns at the macro level. This was intended to give an overall picture of the relative importance of the modes of communication in EE, and hence, guide to answering the question posed in the title: How optimal is multilingualism in EE? All analytical work was done on a specially programmed EXCEL spread sheet.

The third and fourth questions of this research were to be answered specifically from responses of the students being taught by the authors, because these questions demanded testing of teaching improvement actions. As at time of submitting this manuscript, apparent improvements have been effected, but evaluation of their effects is yet to be done because it is intended to be from results of the final evaluation assessment in June 2019.

Results

Figure 1 gives the numbers of respondents from each region and department by 31 Mar 2019. Figure 2 gives an extract of the spread sheet which analysed the responses to yield results of the last row.

![Figure 1: Nature of respondents](image1)

![Figure 2: Extract of spread sheet showing some results on engineering communication methods, and their analysis: W = Wordy Language; P = Practicals/Demonstrations; M = Mathematical/Symbolic; E = Engineering drawing/Pictorial.](image2)

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Responses before validation show communication by demonstrations or Practicals (P) to be the most effective method at 1.9, followed closely by Mathematical communication (M) at 2.0. ‘P’ retains its pole position even in the self-reported preferences, at 1.7, but Engineering Drawing/Pictorial communication (E) appears to edge ‘M’ to compete for the top slot at 1.7. However, looking at the validation part of the spreadsheet, it is clear that ‘M’ is more effective than ‘E’ because of its higher validated ‘Best’ and lower validated ‘Worst’ scores. Wordy communication (W) as is commonly practiced and even advocated - in form of multilingualism - in instruction and assessments is the least effective engineering communication method to these respondents.

The reasons for this could be that learning of Engineering requires development of an innate analytical and creative ability that does not have to - and often cannot - be expressed in already existing words of whatever language. It is best learnt by doing, and not by talking or listening. And ‘doing’ or even observing someone ‘doing’ and thinking about why and how s/he is ‘doing’, has no special language. This explains the respondents’ preference for ‘P’ above any other method. These findings correlate well with those of Jensen and Mosgaard (2015) study in Denmark on multinational Robotics Engineering students doing projects in an English medium engineering faculty. And perhaps Professor Björkman’s work in Sweden on whether fluency in English by both lecturers and students in one technical university affected course outcomes delivery is most instructive: He concluded thus (Björkman, 2008):

“It is remarkable that despite the relatively high frequency of the non-standard forms of English, there is little communication failure because of grammar- or vocabulary-related oddities. The results show a clear tendency by engineers to reduce redundancy and to focus on function regardless of standard form.”

Conclusion

As a conclusion to this part of the study, we acknowledge the simplicity, the convenience, and indeed, the importance of language or verbal communication in engineering education. However, we submit that in a situation of scarce resources – as is the case all over Africa - it would be much better for engineering academics and engineering education administrators to look at the four communication methods and allocate resources in line with their relative effectiveness. Wherever this is not done, but action is directed to development of multilingualism to enhance wordy communication in engineering education, we pose the question of part of the title of this paper: how optimal is multilingualism?

On the last 2 questions, of the study, we found the results on ‘P’ and ‘M’ a bit challenging on some of our Teaching and Learning activities. Some changes were therefore made in the second half of the semester, but their effects are yet to be evaluated.

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Examining the socio-psychological phenomenon of shame in engineering with coupled interpretive methods

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Background

In the present extended abstract, we focus on our methodological choices to investigate shame as a socio-psychological phenomenon in engineering contexts by using two coupled research methods: interpretative phenomenological analysis (IPA) and ethnographic focus groups. Prior work in engineering education research has examined multiple theoretical constructs that are related to the emotional experience of shame, such as marginalization (Foor, Walden, & Trytten, 2007; Godwin & Potvin, 2017) constructions of academic ability (Secules, Gupta, Elby, & Turpen, 2018), and systemic patterns of exclusion that undergird engineering cultures (Foor & Walden, 2009; Pawley, 2019; Tonso, 2006). However, with few exceptions (e.g., Kellam, Walther, Wilson, Gegrow, & Lande, 2015; Villanueva, Campbell, Raikes, Jones, & Putney, 2018), existing research rarely examines the complex experiences of emotions that undergird the everyday experiences of engineering students. And more specifically, there is a gap in existing research in relation to examining the emotional mechanism of shame as it relates to social phenomena of inclusion and exclusion in engineering domains. Thus, in our ongoing investigation, we are studying shame in the context of engineering education (Huff et al., 2018; Huff et al., 2019). Before describing our methodological choices to examine this complex theoretical construct, we first state how we understand shame based on existing frameworks in psychological and sociological literature.

Theoretical Frameworks

From a psychological perspective, shame is a profoundly painful emotion that occurs in a failure to meet others’ expectation (Lewis, 1971; Tangney and Dearing, 2002). In this view, shame is an intrapersonal phenomenon that is felt vividly by an individual and that motivates maladaptive interpersonal behavior. From a sociological perspective, shame is understood to be a “threat to the social bond” (Schef, 2003, p. 255) and is located in particular contexts that weave the fabric of social expectations (Brown, 2006; Scheff, 2003). Accordingly, we frame our investigation of shame in the engineering context, recognizing that while the emotion is ubiquitous in individual-environment interactions, there are significant contours of the emotional experience that may be found within engineering domains. But how might we understand the complex interplay between the individual and intersubjective features of how shame is constructed and experienced in engineering education? In the next section, we
describe the rationale for choosing IPA and ethnographic methods as approaches to comprehensively unpack this phenomenon.

Methodological Approach

Recognizing shame as a phenomenon that was both culturally situated in undergraduate engineering programs and individually experienced, we employed IPA to conduct unstructured interviews with 9 White, male engineering students in the third year of their degrees from two institutions in the United States regarding their experiences of shame in their engineering contexts. IPA is a research method that is specifically designed to unpack individual, lived experience of phenomena through extensive content, linguistic, and conceptual analysis (Smith, Flowers, & Larkin, 2009). We intentionally sampled individuals from the majority race-gender social group in engineering (i.e., White males) in order to critically examine how shame might inform inclusive and exclusive behaviors. However, while using IPA provided provocative insight regarding how shame is felt on a personal level, it is limited in describing how the emotion might serve as a mechanism for creating social expectations that serve to implicitly include and exclude individual from engineering contexts.

Accordingly, we employed ethnographic methods in 10 focus groups of engineering students at the same two institutions in the United States in order to define ways that co-construct social expectations in engineering settings. The focus groups were composed of 3-6 individuals each and were stratified to represent homogenous groups of White, male students (n=5) and groups that were heterogeneous in relation to gender, race, and ethnicity (n=5). The transcripts of the focus groups were analyzed with an ethnographic lens, where linguistic features of the discourse and the content of the conversations were connected to broader sociocultural frames that structurally define engineering settings. The focus group data provided robust explanations for understanding how social expectations, which are connected to shame emotions, are co-constructed within engineering domains, but they are limited in generating insights into the individual experience of shame itself.

Emergent Findings and Insights

The preliminary results of the IPA investigation have been documented elsewhere (Huff et al., 2019) and the results of each phase of the investigation are intended to be documented in forthcoming publications. However, we use this final section of the extended abstract to briefly demonstrate an example of how IPA provided a methodological framework to generate in-depth insight into the individual experience of shame while ethnographic focus groups have provided a way to unpack the cultural experience of the phenomenon. For example, in the IPA investigation, we found that when engineering students experienced shame, they were motivated to reject the emotional experience altogether. Multiple participants described an acute aversion to feeling shame and the desire, as put by Daniel, “to move on.” As put by Sam (pseudonym), the emotional experience was generally deemed to be “just repulsive—foul. Like something was rotten. I didn’t want to look at it. Didn’t want to be part of it.” Thus, through IPA, we were able to see that when the engineering students encountered shame, they were generally motivated to move on from the emotional experience. But what sociocultural patterns might have informed these individual decisions?

Through an ethnographic lens on analyzing focus group, we found a compatible theme to the individual experience of rejecting the pain of shame. The focus groups generated the expectation that, when stressful circumstances arise, they move quickly to the resolution rather than taking stock of the stress itself. For example, in one focus group, a participant discussed the strategy of “compartmentalizing everything,” saying that “as soon you let that wall down and other things start coming in, you’re going to freak out, and you can’t let that happen.” Thus, even in a limited treatment of our preliminary findings, we can see a relationship between the individual experience of shame and how such personal lived experiences might inform broader cultural patterns of the engineering environment.
Based on our early findings, we feel assured that as our ongoing investigation generates comprehensive results through IPA and ethnographic research, we will find more connections between how shame is understood in the sociocultural contexts and how it is experienced within individuals. And indeed, we aim for our collective findings to not only generate theoretical insight on shame in engineering settings but also methodological insight in investigating socio-psychological phenomena.

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Factors in engineering education that influence social justice

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Abstract: As the human population continues growing, the challenges are increasingly complex and systemic for engineering (Cheville, 2012). Therefore, the important role that engineering education plays is implicit, since engineers possess the knowledge and the skills to generate a profound influence on society and human life, both positively and negatively (Cardella, Zoltowski & Oakes, 2012). However, this statement does not precisely consider the occasions in which engineering interventions have perpetuated social injustices. The above is the result of the combination of different factors that define a significant part of the engineering culture. In that regard, a conventional content analysis was performed, prompting to obtain a preliminary analysis of factors in education and practice of engineering that influence social justice.

Context

The challenges for engineering are complex and systemic, this clearly reflects the important role of engineering education, because engineers influence on society and human life, both positively and negatively (Cardella et al., 2012). However, Cardella et al. (2012) does not precisely consider the occasions in which engineering interventions have perpetuated social injustices.

Throughout history, several scenarios have been witnessed in which the development of projects of different magnitude has been problematic, and sometimes, their results have not been satisfactory or end up being classified as failures. These are the cases of El Cajón in Honduras, the project to modernize the brick kiln in Pakistan and the installation of mills in several villages in Mali, among many others. These situations had in common the little involvement of the communities to which the project was directed, due to the lack of fundamental skills such as contextual listening and assertive communication and also due to the influence of assumptions and paradigms that characterize the acting engineering (Lucena et al., 2010). Besides, there are engineering interventions that have not been failures but, they have perpetuated social injustices. For instance, the case of TransMilenio in Bogotá (public transport), where disabled citizens were framed as a menace to the system, referring to the fact that construction of accesses for people in wheelchairs in all stations would endanger its economic sustainability and this would imply higher prices for all passengers (Valderrama, 2012).

These situations are the result of the combination of different factors that define a significant part of the engineering culture, which takes meaning through its ideologies, mentalities, knowledge, values, norms, competences and practices. This culture is promoted mainly in the formal education of the engineers, starting with a first approach to the beginning of their training, reinforcing it during their academic career and finally, achieving consolidation and
conservation throughout their work experience, which leads to perpetuation of their culture in generations of engineers (Cech, 2013).

Purpose

This investigation is the beginning of a study that will contribute to research in social justice and engineering education fields. This discussion is beneficial to identify factors in engineering education, which are mainly framed in the culture of engineering profession and have generated a poor cognitive recognition of the reality of social injustice. With regard to the above, this study aims to answer the research question: What factors in engineering education influence the perpetuation of social justice or injustices?

Theoretical framework

The engineering curriculum according to G. Downey, has been characterized by accentuating a hierarchy of knowledge, having as main axis the resolution of technical problems and engineering sciences, followed by the design process and moving away notoriously the social sciences and humanities courses (Lucena et al., 2015). A manifestation of this generalized technical/social division is the tendency to disassociate the practice of engineering from the context in which that practice is carried out. This approach transmits to the students that the information on the context of the application of the engineering experience is secondary to the technical information (Nieusma, 2011).

This culture of disconnection is the grouping of beliefs, meanings and practices that defines the way in which members of the profession conceptualize their professional responsibility towards society and, together with other elements of the professional culture of engineering, helps to frame the daily activities of definition and solution of problems (Cech, 2014). The culture of disconnection has three ideological pillars: depolitization, technical/social dualism and meritocracy. First, depolitization is the notion that the domain of engineering is purely technical, therefore, it is considered apolitical and asocial. Second, technical/social dualism refers to the aforementioned cognitive separation of technical and social competences in engineering education. Finally, meritocracy, which is considered as the belief that those who succeed in life is due to their individual talent, training, motivation and hard work (Cech, 2013, Cech, 2014, Lucena et al., 2017). These three ideologies point to a culture of disconnection that defines considerations of social welfare separate from the professional work of engineers (Cech, 2014).

Moreover, the culture of engineering is also influenced by inherent normality and superiority. According to some experts, they recognize that there are still acts of discrimination and oppression, increasingly common in more subtle ways, which contribute to the generation of unconscious biases (Lucena et al., 2017).

Methodology

A conventional content analysis was performed (Hsieh et al., 2005), prompting to obtain a preliminary analysis of factors in education and practice of engineering that influences social justice. This research was based on the analysis of related documentation about Social Justice, Engineering, and Engineering Education. Given the strong link of the Journal of Social Justice, Engineering Education and Peace within this field, their references were analysed. In addition, two search equations were used in SCOPUS and, it is important to mention that some references were recommended from experts on this field. From that point, a comparison of concepts and collection of different ideas were carried out.

Preliminary findings and discussion

The factors that were identified are evident in engineering education, which consequently is reflected in the practice of engineering and, then, it becomes part of the culture of
engineering profession. The ideological pillars have generated a culture of disconnection which has marked the way in which the members of the profession conceptualize their social responsibility. The normality and superiority foster acts of discrimination and oppression, increasingly common in more subtle ways and contributes to the generation of unconscious biases. In the literature, these factors have a strong relationship with each other but are developed separately according to the purpose of each reference. As a result, it can be concluded that there is a contribution to answer the research question posed for this study.

Conclusions

According to Ramzi et al. (2016), the involvement of social justice in engineering is considered as the missing link between theory and practice, and it would allow opening the discussion of what engineering is and should be, conceptually, pedagogically, and in terms of professional practice, this being much related to the purpose of this research. As a beginning of a study, the conventional content analysis performed allowed us: (1) to confirm novelty on this approach since the references analysed develop those factors in a separated way and (2) to observe that the engineering education has been moving towards the rise of implementation of social justice within the curriculum due to the growing number of articles referring to this topic in the recent years.

References


Exploring the use of metacognition in learning science concepts

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Abstract: Research on ‘how people learn’ identify metacognition and self-regulation as some of the key factors which changed conceptions of learning. Accordingly, research in science education has realised the potential metacognition has in promoting learning, however, in STEM education, studies on metacognition have focused more on science and mathematics, and to a lesser extent on technology and engineering. The purpose of the intervention was to determine the effects of metacognitive thinking on the understanding of science concepts in a Natural Sciences and Technology module. The study employed a quasi-experimental, mixed-methods research design with pre-post tests on metacognitive awareness, disciplinary understandings of the science concepts of floating and sinking in water, focus group and individual interviews. The intervention consisted of a sequence of instruction to scaffold metacognition and certain science concepts, as well as practical science investigations coupled by group discussion, written explanations and reflections.

Introduction

This paper presents work in progress of a study exploring the use of metacognition to learn the science concepts of floating and sinking when the medium is water. While the study is set within the field of science education, it is hoped that the lessons generated from this research can also be used to reimagine and inform the conceptualisation of student learning in engineering. Furthermore, natural sciences or physics, under which floating and sinking are explored in the context of this study, also forms part of the theoretical base of engineering education; and the concepts of floating and sinking can also be learned and explored in other engineering situations.

Context

Research on ‘how people learn’ and ‘how learning works’ identify the awareness and application of metacognitive thinking processes as key indicators of academic success and lifelong learning (see Bransford, Brown, & Cocking, 1999; Ambrose, Bridges, DiPietro, Lovett, & Norman, 2010). Metacognition places emphasis not only on what to learn (content/cognition) but also, on how to learn (meta-cognition). Metacognition refers to thinking about cognition and the products of cognition, usually involving monitoring and choosing among tactics and strategies (Winne & Hadwin, 2010). A more classic definition describes metacognition as the knowledge of cognition and regulation of cognition (Flavell, Miller, & Miller, 2002). In relation to learning, metacognition is about ‘knowing how to learn’ and ‘thinking about learning’. Knowing what to learn and how requires students to reflect consciously on the given task, survey what they already know (monitoring), devise a plan or strategy for solving the problem, describe what they are doing and why, talk about the feelings they experience as a result of the learning task and use this information to enhance their performance (Georghiades, 2004a). Thus, the ability to know and learn how to learn aids the process of active, deep, and meaningful learning.
Conceptual framework

Metacognition has three main components namely, ‘knowledge of cognition’, ‘regulation of cognition’ as well as ‘cognitive and affective experience’ (Zohar & Dori, 2012; Flavell, Miller, & Miller, 2002). Knowledge of cognition consists of: (1) declarative knowledge which is the factual knowledge needed before processing or applying critical thinking and problem solving; (2) procedural knowledge which is the application of knowledge in order to solve a problem; (3) conditional knowledge which involves determining under what circumstances processes/skills should transfer and knowing when and why to use learning procedures. Regulation of cognition consists of: (1) planning which is about goal setting, activating relevant background knowledge and budgeting time; (2) monitoring which includes self-testing and checking comprehension; and (3) evaluating which is about analysing performance and the effectiveness of strategies, during and after task performance. Metacognitive experiences are exemplified by feelings of puzzlement, surprise or epiphanic moments pertaining to understanding or not understanding a particular learning event.

These components and sub-components of metacognition have been gradually integrated in the curriculum of Natural Sciences and Technology, a module taken by first year Intermediate Phase students registered for Bachelor of Education studies at a comprehensive university. The conceptual difficulty associated with learning certain science concepts, and the need to promote conceptual understanding on floating and sinking in water have been the motivating factors for embedding metacognition in instruction and science investigations (Heywood & Parker, 2012; Zohar & Dori, 2012). As recommended in previous research, which reports significant gains as a result of embedding metacognition in course content, the study (i) took place over 15 consecutive weeks; (ii) students were informed about the usefulness of metacognitive activities so that they may put in the initial extra effort, and (iii) metacognition was taught explicitly and modelled when applied generically and in domain-specific cases such as developing scientific reasoning and procedural knowledge associated with performing scientific investigations (Veenman, Van Hout-Wolters, & Afflerbach, 2006).

Research design and methodology

The purpose of the intervention was to determine the effects of metacognitive thinking on the understanding of science concepts. The study employed a quasi-experimental, mixed-methods research design with pre-post tests on metacognitive awareness, disciplinary understandings of the science concepts of floating and sinking, focus group and individual interviews on students’ epistemological beliefs about learning science as well as their thinking and reasoning during scientific problem solving. The intervention, carried out between the pre- and post-tests, consisted of a sequence of instruction to scaffold metacognition and certain science concepts, as well as practical science investigations coupled with group discussion using Accountable Talk (Resnick, Asterhan, & Clarke, 2015), and written explanations and reflections. The writing and reflection sheets provided metacognitive scaffolds during students’ independent group investigations and prompted students to predict, test, observe, and explain verbally and in writing.

The series of investigations started with exploring floating and sinking using everyday objects with various shapes, sizes, material and weight, such as small plastic bowls, empty cartons of milk, bottle tops, paper clips, pieces of wood and stone. Second, students measured the mass and volume of lead sinkers, square and rectangular blocks made of different materials (iron, wood, polystyrene, wax, etc.) and the volume of water displaced by the object. Third, students explored whether shape influences floating or sinking and whether things are really lighter under water or not. Fourth, using an inflated balloon pushed into water, students had to explore what happens. This exploration, which provided them with another opportunity for metacognitive experience, exposed them to the notion of forces. Fifth and last, students performed the Cartesian diver experiment and had to explain the behaviour of the ‘diver’ when the bottle was squeezed and released, thereby exploring the effect of pressure in water. Students’ group discussions and science investigations were audio and video-recorded in order to assist with data analysis and interpretation.
Preliminary results and discussion

Given that the study is work in progress, post-test data has not yet been generated in full and it is not possible as yet to provide quantitative results on the pre-post tests on metacognitive awareness and the test on the scientific understandings of floating and sinking. But, a preliminary qualitative analysis of a sample of the pre-post-test on the scientific understandings of floating and sinking suggest that students have over time, significantly improved conceptual understanding in terms of floating and sinking. The written data (predictions, observations and explanations) generated during science investigations indicate that students had developed a richer repertoire of linguistic and scientific discourse in explaining the factors and conditions which determine whether certain objects will sink or float. During the first investigation, it was common to hear and see written explanations attributing floating and sinking to the weight of the object and to density, but over time, students learned to explain floating and sinking through displacement, and without using a formula for density. Individual interviews with some of the students reveal that they learned and felt what is meant by gravitational force, buoyant force and resultant force. The notion of forces was not only a theoretical concept but it was experiential and that influenced students’ conceptions of learning. Some admitted to have never heard of the term buoyancy until reflections on the previous experiment were done in order to consolidate learning. The same students explained that they had observed the workings of what may be called the buoyant force but did not know the word for buoyancy. Students also exhibited enjoyment and keenness during investigations.

Conclusion

It can be concluded that in terms of understanding the science concepts of floating and sinking in water, most students progressed from ‘naïve explanations’ based on intuitive explanatory frameworks towards more scientifically acceptable explanations, using the concept of water displacement and related forces (Heywood & Parker, 2012).

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Developing a Conceptual Model of Construction Employees’ Professional Values

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Abstract: As the construction industry faces increasing demands from society, it must recruit and retain employees to sustain and expand the current workforce. However, few research studies seek to understand employee career satisfaction within construction, which can be linked to professional formation and the expectations set forth for students entering the workforce. To promote professional formation and better prepare students for a career in construction, scholars must consider the complex variables and contextual influences that shape current employees’ career satisfaction. Prior work in this area adapted Brown’s Value-Based Theory and distributed a survey to 314 construction professionals in the US to better understand the values of employees when choosing to enter and remain in construction. This paper expands on this work to introduce a conceptual model of employee professional values to serve as a guide for practitioners and scholars to promote formation for current and future construction professionals.

Context

The industry is calling for different competencies due to the high and complex nature of construction projects. As such, an undergraduate degree is not only charged with providing professionals the resilience to remain in a job, but instilling the competencies to perform successfully. However, high turnover rates in construction have hindered the ongoing development of construction companies, prompting scholars and practitioners to develop and adapt retention and recruitment strategies for a future workforce. Gaining an improved understanding of current employees’ values, particularly those related to retention and recruitment, can inform practices of practitioners and scholars and facilitate their development and support of structures within and outside the university for prospective employees. Many studies in industrial and organizational psychology have broadly investigated the influence of employees’ values on career choice; however, few studies have been contextualized in construction, making it difficult to directly apply and operationalize emergent research findings to the construction workforce and education.

Purpose

As part of a larger investigation to understand construction employees’ values when making career decisions (Bae et al., 2019), this study sought to inform the professional formation of
future and current construction employees by examining the research question: What are the characteristics of professional values which influence construction employees’ career choice or career satisfaction?

Theoretical Framework

Brown’s Value-Based Theory of Occupational Choice, Satisfaction, and Success (Brown 2002) provides a framework for understanding individual values that inherently drive career decisions. By delineating factors influencing employee satisfaction, Brown constructs three overarching values (i.e., work, cultural, and life role values) that influence individuals’ decision-making processes of choosing a future career. To thoroughly comprehend the aforementioned values, Brown expands his framework to include external factors such as socioeconomic status (SES), family influence, history of discrimination, gender, mental health, access to information, and self-efficacy. To gain a greater understanding of the values that construction employees seek and expect to be satisfied in the workplace, this paper applied Brown’s Value-Based theory as a theoretical framework to develop better ways of preparing students for the construction workforce and for industry to retain them.

Prior work (Bae et al., 2019) has redeveloped Brown’s theory and renamed each value with a definition. For example, professional work value is defined as intrapersonal values that an individual believes should be satisfied through the participation of work role. Professional cultural value is defined as the interpersonal values that individuals believe should be fulfilled through interactions or engagement with workplace. Lastly, professional work-life balance value is defined as the combined inter- and intrapersonal values that an individual maintains to balance personal life with professional life.

Approach

To investigate construction employees’ values, this study analysed the responses to two open-ended questions included in a survey distributed to 314 construction professionals from 37 companies in the United States. In the survey, Q1 identified values that construction employees perceived as lacking in their companies, while Q2 identified values that attracted individuals to seek employment at their current construction companies. Each response to these text-entry questions were analysed using an inductive qualitative research procedure (Charmaz, 2014; Thomas, 2006) to identify emergent and unanticipated values that influenced employees’ career choice or career satisfaction in construction.

Results and Discussion

Our approach yielded two overarching themes captured by three types of employee values demonstrated in a conceptual model (shown in Figure 1): 1. Professional work values are closely related to both professional cultural values and professional work-life balance values; and 2. Professional cultural values and professional work-life balance values were not related with the exception of “reputation,” which was linked to all three value types. The conceptual model illustrates the relationship between each overlapping value. Based on the responses from the two survey questions, sub-values pertaining to each overarching value were analysed and are represented in Figure 1 as the most-prioritized values of construction employees. For example, Communication (11%) and Control of Work Schedule (6%) – values that were identified as lacking in a company – overlapped professional work value and professional culture value while Reputation (19%) and Sense of Belonging (17%) – values that drew employees to work as their current company – overlapped professional work value and professional work-life balance value, with an exception of Reputation which overlapped all three values. These sub-values were double or triple coded because they simultaneously satisfy two or more professional values and correspond to the definitions.
The sub-values can be interpreted as the employees’ key drivers to enriching their career satisfaction. For example, Communication and Sense of Belonging are two sub-values categorized under the professional work value and the professional cultural value. These two sub-values characterize respondents’ desired or perceived working environment to have a mutual vision for work, an effective knowledge transfer system, and an interactive relationship within their workplace. Further, Control of Work Schedule captures respondents’ desired sub-value to have flexibility in their work schedule as to better balance work and personal life and optimizing productivity. Reputation, in particular, is the one and only sub-value that overlaps all three values. Respondents described that reputation of a company helped them make a career decision because they thought a reputable company could provide more opportunities for career advancement and serve as a way to promote socio-economic status. Additionally, respondents equated a reputable company with the ability to serve their employees honourably and facilitate a loyal relationship with them. However, future research is needed to fully understand the meaning of reputation, which this study could not attain due to respondents’ limited descriptions.

Conclusion

A conceptual model of three overarching values contextualized in construction can contribute to scholars’ and practitioners’ understanding of employees’ values that influence career choice and career satisfaction. While future work is necessary to better understand employee values of reputation, this research illustrates relationships among and across values that both contribute to and expand Brown’s initial Value-Based Theory (2002). From this work, scholars and practitioners in both academia and industry can use the identified sub-values to inform strategies for professional preparation as well as recruitment and retention strategies within the workforce.

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Grit as a key success indicator in engineering postgraduate studies, or: marks aren’t everything when choosing a student

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Abstract

The choice to do a postgraduate (PG) research degree (for a potential student) and to supervise a new PG student (for an academic) is an important one. There is unfortunately a dearth of information on what to make this choice on; most academics will focus on the marks achieved by the prospective student in their undergraduate degree, and perhaps an interview. A potentially useful measure in this space is ‘grit’, which research students will need in order to succeed in their projects. There are (comparatively easy to test) sociological indicators of a person’s grit, which may be of use in estimating a potential student’s suitability for PG studies. This (ongoing) study uses self-administered grit-measurement tests, focus group interviews with both supervisors and students, and longitudinally achieved outcomes, to link PG success with measured grit, with the goal of suggesting a tool for prospective students and study leaders to use.

Introduction and aims

Traditionally, academics as supervisors select prospective postgraduate (PG) students primarily on the marks they achieved in their undergraduate degree. For the most part this is a fairly reliable measure of a student’s aptitude, however, there are many anecdotal cases showing the opposite trend – ‘good’ students perform poorly in PG studies, and ‘poor’ students exceed expectations and produce excellent work. And certainly, while not all students are the same (and neither are the projects they embark on), the distribution must in some way match up with the need if both student and project are to be successful.

There is a dearth of literature examining other potential predictors of PG success, and yet taking on a PG student is an expensive commitment (both in terms of research money and supervision time). Alternative measures which might predict student success would be very useful. One potential measure is ‘grit’ (defined as “perseverance and passion for long-term goals” (Angela L. Duckworth, Peterson, Matthews, & Kelly, 2007)). There are sociological indicators of a person’s grit, which may be of use in estimating a potential student’s suitability for PG studies. There is also some indication that ‘motivation’, which has been shown to be key to success is tied to ‘grit’ (Wright & Cochrane, 2000) – these may be sides of a coin.

Of course, there will never be a single measure which dictates or defines the success of a person, or their suitability for a particular path, and we must be careful not to fit anecdotal data to broad definitions of success (Koen, 2007). However, just because a measurement is noisy, and correlation difficult, does not mean that there is no value to be gained from an insight into this particular attribute. Grit is an important aspect of PG research, and while the answers are not yet in on whether grit can be enhanced, trained or mentored, it may be an aspect of personal development which should be more closely examined in PG admission and study.

This study aims to examine two key aspects of grit in PG chemical engineering students: firstly, we will attempt to determine whether a link exists between PG success and grit, using Duckworth’s self-reporting grit scale (which our students undertake as part of their ‘introduction to research’ course), and MEng and PhD results. Secondly, the progression or change of grit
through a PG student’s research career will be examined, to see whether PG studies can enhance (or repress!) grit scores. Other factors, such as demographics or being a first generation student, will also be considered in the data collection, and this data used to cross-correlate.

While it is very likely that grit is just one factor in an array which can determine whether a student will be successful or not, the relative ease of use of the predictive tool is attractive. If some correlation can be found (even if it is somewhat confounded by other factors), then this will be a useful tool in a suite that can be used by supervisors (and prospective students) for determining fit in postgraduate research posts.

**Context**

This work takes place during postgraduate degrees (MEng or PhD) in chemical engineering, as full time research degrees, within a South African research intensive university. As such, while there are certainly context and societally specific aspects to the cohorts, research conducted with these postgraduates is likely to be broadly applicable to other global institutions and postgraduate engineering programs.

**Methodology and framework**

The primary theoretical framework used in this study is Duckworth’s ‘grit’ scale, which has been elucidated in other spheres of sociological research (A. Duckworth, 2016; A. Duckworth & Gross, 2014; Angela Lee Duckworth & Quinn, 2009). This measure (a self-reported quantification) will be triangulated with examination results, student and supervisor focus group and interview feedback.

Using a longitudinal study approach, all new incoming PG students in the Department, now perform the grit score test (A. Duckworth, 2019), as a self-evaluation (on a Google Form). This is used as a bench-mark for incoming students’ grit. Students will be requested to redo the test at the end of their studies, to examine the influence of the PG degree on grit.

Focus group interviews will be conducted with groups of PG students, to elicit discussions around key personality traits, and states of mind, required for PG work.

Interviews will be conducted with supervisors within the whole engineering faculty, to examine supervisor perceptions of ‘the ideal PG student’, and gather insight into student selection methodologies.

Of course, the corollary to asking the question ‘what is an ideal student’ might bring to the fore the supervisors’ biases in relation to notions of identity, background, and culture, and that graduate engineering students are all different, bringing a diversity of skills, talents, and traits. We should not seek to choose a static ‘ideal student’, but it may be the case that ‘grit’ is a cross-cutting measure, which is why we intend to triangulate the qualitative results of supervisor interviews, with other measures (both qualitative and quantitative).

Exit interviews and surveys for graduating postgraduates are already performed in our department looking at demographic information, and this will be included in the study. Factors such as ‘first generation student’ are likely to also play a significant role in student success, and if this study is to disentangle these factors they must first me noted.

**Preliminary Results**

This is an ongoing study, which also by necessity will operate over the course of several years. However, some key results that can already be drawn on include the following:

Discussions with supervisors indicate a split on perceptions around PG selection; some supervisors consider undergraduate results as key, while other supervisors value ‘chutzpah’, ‘tenacity’, ‘innovation’, or ‘problem solving’. Many of these ideals are co-related to grit. We can
hypothesise that the divide in supervisor preferences is a reflection of the type of research they conduct, however, this remains under investigation.

The grit scores of new incoming PG students (we have two years of data thus far, n=70) are for the most part high, in comparison with the general public (making use of Duckworth’s openly accessible data). However, while most are high, there is still significant variation between students. Whether this correlates to success is yet to be determined.

While we do have data on intermediate achievements (in the form of the research proposal – this consists of a substantial literature review, proposed objectives, methodology, research progress and proposed workflow), we do not yet have evidence on graduations. In general terms there appears to be a lag which low grit-scoring students show at the proposal level while high grit-scorers produced better research proposal documents. However, this document is very early in the MEng program, and so may not be a good indicator of final success.

A key determinant appears to be intrinsic motivation (which corresponds well to the literature on success in research degrees (Guerin, Jayatilaka, & Ranasinghe, 2015; Kang et al., 2009)), however, motivation can be difficult to measure at the point of appointment – and thus the connection to grit may speak to this intrinsic property.

Conclusions

To conclude, the field of grit is currently of great interest in many fields. One field which is yet to be explored is its use as a predictive (and potential selective) tool in PG success. This article has hypothesised that grit will be an interesting, and hopefully reliable, measure of success in PG studies. It also puts forward that one of the key purposes of PG study is to enhance, train, and enable grit in students.

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Professional engineering work: What knowledge matters

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Abstract: This study is based on an analysis of in-depth interviews with recently employed graduate engineers. The study investigates the relationship between epistemic relations and social relations in professional engineering practice. Although only in the initial stages of analysis, preliminary indications suggest that the social relations evident in professional interactions might be overshadowing the more implicit nature of principled knowledge.

Introduction

Engineering program designers and accreditation bodies have been struggling with finding an appropriate balance between enabling skills and technical knowledge in formal engineering education (e.g., Mann, 1918; Grinter, 1955). The 1990s saw a significant shift away from a focus purely on specialised disciplinary knowledge to acknowledge the importance of the social dimensions of successful professional practice. Two obvious markers are the increase in design and service-learning projects, and outcomes-based accreditation. We explore the relationship between specialised knowledge and social skills in the engineering workplace. Our analysis is founded on the specialisation dimension of Legitimation Code Theory (LCT) (Maton, 2014). LCT is associated with particular methodological and analytical assumptions that provide organising principles for understanding practices, dispositions and contexts.

Theoretical Framework

LCT (Specialization) develops the argument that all knowledge practices have two dimensions, what you know (epistemic relations - ER) and who you are and how you do things (social relations - SR). The question that this analytical framework seeks to answer is: Which relationship/s legitimate any knowledge practice? It takes as given that all knowledge practices include both ER and SR, but that the importance of the relative strengths of ER and SR in ‘legitimating’ practices vary across different practices in different contexts. When ER is ‘stronger’ (ER+) specialised engineering knowledge legitimates practice. When ER is ‘weaker’ (ER-), knowledge appears to be less important. When SR+ personal attributes (who you are, how you do things) legitimate practice. ER and SR vary independently.

A study of design practices in architecture, fashion, engineering, and media (Carvalho, 2010) coded engineering ER+/SR-; specialized knowledge (what you know) matters (ER+), while who you are (anyone can ‘be’ an engineer) is less important (SR-). But the introduction of graduate competencies indicates a strengthening of the social relation (SR+). Simultaneously, specialized knowledge, while not absent, has become more implicit (ER-). This indicates what Maton (2014) calls a ‘code shift’. (ER+/SR- to ER-/SR+). Passow and Passow (2017) reviewed 52 studies investigating generic graduate competencies and their relative importance in engineering practice. They found that problem solving, communication and teamwork (SR) were ranked at the top with engineering science (ER) of less importance. This suggests that legitimate engineering practice might be coded (ER-/SR+). Qualitative studies did recognise the generic skills are inseparably intertwined with technical competence (ER+/SR+). Our study explores the intertwining of epistemic relations (ER) and social relations (SR).
Approach

As a work in progress we present preliminary coding from a single in-depth interview. Although incomplete we do offer some observations on what this data might suggest about what it means to be recognised as a ‘legitimate’ engineer. The analysis followed a standard LCT methodology, where LCT explicitly provided the framework for organising the data and filtering relevant extracts. Although directed by notions of epistemic and social relations, the coding themes are developed in a dialectical relationship between theory and data.

Findings

The preliminary findings are constructed from quotes from a single in-depth interview with a graduate engineer (MSc Civil Engineering) in his 2nd year of employment. The project under discussion was the structural design of 10 blocks of 4 story apartments, suspended over an underground parking lot.

The first vignette focuses on the social relations, followed by quotes that illustrate the types of social relations that we identified through a thematic analysis of the data:

At the beginning I worked closely with the senior engineer responsible for decisions and contact with the client [..] with me shadowing [..] and learning [..]. You need to build up experience so they can trust you. After 2 or 3 months I took over the project. His involvement came down to me asking questions, but basically, I ran the project from that point onwards. [..] I was now engaging with the client, about queries, getting the architect's drawings, [..] and doing the design, passing it on to the detailer so he can draw it, issuing those drawings I was basically the main contact for the project.

Central to the social relation was to be recognised as trustworthy. The categories we identified were:

SR: Interaction with people and communication

How to interact with people [..] how to engage with the client, [..] more professional communication, [..] meeting and conversing and being appropriate and answering e-mails that are rude to you, it’s a huge part of engineering and engineering is business, having a business relationship with people.

SR: Personal responsibility and communication

You give it to the detailer to draw, [..] I check that he has done what I have designed, [..] There are often mistakes not that the detailer cannot do his job, but the communications with such fine details is very difficult [..] they haven’t quite understood what you have drawn, you have changed something.

SR: Seeking advice and receiving criticism constructively and communication:

Asking questions [..] One of the senior engineers checks it, not all the details just a general thing saying I think you need to do this, based on their experience saying I think we need to add this or that.

SR: Taking initiative

Nobody has time to babysit you and tell you this is how you go about a design of a concrete beam. If you don’t know what you are doing, you need to figure it out, go onto the internet, find places where people tell you how to look at beams and critically analyse.

SR: Being flexible:

The problem is that nothing is finalised so it’s a constant back and forth between us and architects, mechanical, electrical, land surveyors, all sorts of people making it more complicated.

These are the sorts of personal characteristics that have been identified as graduate competencies expected of graduate engineers in the workplace. They have been formally and explicitly introduced into accreditation requirements (SR+).

The second vignette focuses on the epistemic relations and gives a sense of the range of ‘types’ of knowledge that ‘legitimate’ engineering practice.
First, we get the architect drawings do the initial assumptions. Prelim layout where we plan columns, beams, a thick slab or a coffer slab. deciding what is reasonable, loads, sizing, steel or concrete. It comes down to experience. Now that I have done this project, I have grappled with these ideas, I now know adding loads to this kind of arrangement is going to affect the moment. I know it because I have played around with it, learnt how structural systems work, how stresses transfer through concrete [etc.]. The things you learnt from the structural courses are useful [but] I will never go and view those calculations. You think I have to know how to design a beam, but the actual design is simple once you have done it once you can do it a million times.

An important observation from the above narrative is the way in which principled theoretical knowledge takes a different form than that presented at university and is more tacit (ER-).

ER: Principled reasoning
Understanding forces and moments; a load here is that going to make the moment more or less here That is an intuitive thing you have got to be able think how is it without doing calculations, you get that through experience but it also comes from being taught the principles.

ER: Procedural reasoning
if talking structural design, that is doing the calcs, that is doing the sizing the actual design of say of how much rebar or something simple, once you have done it once you can do it a million times.

ER: Practical reasoning
You can’t have columns going all the way down into the basement, otherwise there would be no space to drive. Now we need the second column, we can’t fit, it is going to take up a parking bay.

ER: Rules of thumb
There is a rule thumb: 30 to 35 metres for a 10mm joint which is the norm.

Tentative insights and preliminary suggestions
Our conclusions are tentative; however, we argue that they offer some food for thought. Firstly, the social relations seem to dominate engineering practice. They ’stand out’ and legitimate practice (SR+). ER happen ‘in the background’, they are not always visible (ER-). This makes the dominance of social relations in curriculum design and accreditation dangerous if stripped of knowledge. Secondly, experience is enhanced by principled insights. If education is reduced to procedural calculations it is not surprising that ER are undervalued in practice, contributing to perceptions of the irrelevance of theory in education. Finally, one needs to recognise the contextual situatedness of the social relations. An academic setting is contextually different to the workplace context. One has to ask, what social relations are we developing in the academy and how transferable are they into the workplace?

References
Reflection on strategies and interventions used to reduce dropout in engineering first-year courses: A case of Extended Curriculum Program

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Abstract: This paper is a reflection on strategies and intervention programs implemented at the Department of Chemical Engineering Extended Curriculum Program (ECP). The ECP is designed to provide support to students who come from previously disadvantaged backgrounds, who meet the minimum requirement to enter the university’s engineering programs. Various interventions have been implemented to support them in courses, and this reflection highlights the success and limitations of these interventions. Finally, a case is made for proactive intervention that provides students with psychosocial support.

Keywords: Wiley Plus, clickers, diagnostic test, Facebook, psychosocial support, WhatsApp

Context
South African universities are still facing challenges with a high dropout of first-year students (CHE, 2016), and students entering engineering programs are not spared. This challenge researchers have laid at lack of smooth transition between high school and university due to knowledge content gap on courses such as mathematics and physics (Basitere & Ivala, 2015). Some of the challenges have been attributed to students learning styles (Basitere & Ivala, 2014), while others have attributed this to issues relating to cultural capital that may not be aligned to that of the university (Yosso, 2005) for reasons that are historical to the South African context. Much of this non-alignment result in students feeling alienated and struggling to assimilate into the university culture. The challenges listed above make it difficult for some students to transition smoothly into the university, and such, programs such as ECP are tasked to provide support interventions that minimize their effect on students success.
Methodology

We reflect on strategies used during accepting incoming ECP students, and on the knowledge content interventions designed using Bernstein’s (1971) theory of pedagogic device for curriculum reform, and Laurillard’s (2002) conversational teaching and learning framework for effective use of learning technologies. The ECP accepted incoming students with the minimum NSC score level 4 (50%) for mathematics, physical science, and English. Students were required to write mathematics diagnostic test to determine mathematical knowledge gaps that may exist from their learning of mathematics in high school. The lecturer then used the outcome from diagnostic test to design intervention programs as follows: 1) the re-teaching of the content knowledge gaps through autumn school 2) the use of adaptive learning technology Wiley Plus, which was used to provide students with online proficiency test and instant feedback on formative assessment, and online resources such as e-book, animation, 3) use of social media Facebook and WhatsApp, which promoted students’ engagements and collaboration in mathematics course and 4) the use of clicker technology, which allowed students’ engagements and peer learning in the classroom.

Results and Discussion

The results from evaluating these intervention programs indicated that they did play a role in improving students’ success in the ECP. The diagnostic test allowed the lecturer to identify mathematical knowledge gap and sequence knowledge area to align with university mathematics content knowledge area. The inclusion of technology the use of Wiley plus assisted students to gauge their proficiency on the content being taught through instant individualized feedback. The use of Clickers assisted with social cohesion and made students feel valued in the classroom. The use of social media Facebook and WhatsApp provided students with further a platform outside the classroom of engagements and collaboration in a mathematics course. Moreover, the technology interventions provided the space for the lecturer to reflect on his teaching, students learning, and he could use this information to timeously intervene and modify the description on knowledge content taught in the classroom as described by Laurillard’s (2002) conversational teaching and learning framework.

Some challenges were identified with the implementation of technology use: 1) the use of adaptive learning technology limited students who did not have access to
personal computers and internet data – this resulted in the digital divide, as students with resources or who reside on campus could access the university computer laboratory were able to replicate their online scores on paper-based assessment compared to those who didn’t have. 2) It was also found that the knowledge content alone was not sufficient to remedy drop out in the course, as students were found to have other challenges that are psychosocial.

Conclusion
A reflection on the various intervention programs to reduce dropout in the first-year course indicates that, as much as improvements were noted, knowledge content interventions alone are insufficient in providing the student with support. As such, an intervention that provides students with proactive psychosocial support for life issues challenges that permeate into the academic performance needs to be considered. Such an intervention is currently being piloted in the ECP.

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Challenges and solution in an international collaborative aircraft design education project

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ABSTRACT: Curriculum integration of a multi-national multidisciplinary, vertically integrated engineering design education project poses specific challenges and opportunities. An international student team AREND (Aircraft for Rhino and ENvironmental Defense) was formed to design, build and fly an electric unmanned aerial system (UAS) in support of anti-poaching operations conducted by rangers in South Africa. Integrating the project into existing project based modules at the University of Pretoria allows for students to gain experience in systems engineering design of a small aircraft, and provided an opportunity for the students to learn skills in global research and development collaboration as well as professional skills better preparing them for industry. Independent global team organization requires a global project manager with excellent personal skills and understanding of the system engineering process to develop a successful collaborative work environment.

Context

The AREND project focuses on design, build, and test of an unmanned sensor aircraft solution to detect and distinguish humans and large animals such as rhinoceros and elephants in harsh environments. Team AREND consists of 4 Universities, on 3 continents, with undergraduates, post-graduates, staff and local industry partners (Koster et al., 2016). The project functions as a multi-national, multi-disciplinary, vertically integrated engineering design education project developed within the Mechanical and Aeronautical Engineering Department at the University of Pretoria (UP). University of Colorado and the University of Stuttgart already have existing structures within their post-graduate courses to accommodate such projects, which was significantly different to the structure at the University of Pretoria.

In 2014 when the collaborative effort started, the project was not integrated into the curriculum at UP. We recruited student volunteers, but without formal assessment, we were unable to rely on these students for the international team deadlines if they coincided with local course or module deadlines. This extended abstract gives a short reflection on the integration and associated challenges of a program like AREND, into the curriculum of the Mechanical and Aeronautical Engineering degree.

Purpose

The main purpose was to develop an assessable structure within the existing curriculum of the Mechanical and Aeronautical Engineering to enable multi-national, multi-disciplinary, vertically integrated engineering design education projects. It was considered whether such an integration is possible within the assessment structures, which have to follow specific Engineering Council of South Africa (ECSA) outcomes and how challenging this process would be. Allowing for these vertically integrated projects allows for authentic innovative design education if uninhibited by too stringent outcome based requirements.
Approach

Initially the students involved from the University of Pretoria were all final year Mechanical engineering students who volunteered to help to get some experience in an international aerospace design project. Of course students would prioritise their assessed courses over the volunteer project which led to the decision to find a way to make the project assessable. The Department of Mechanical and Aeronautical Engineering has existing design MOX410 and research project modules, MRN412 and MRN422, and so I decided to cast my projects within smaller design and research project components of AREND. These projects are then directly assessed on ECSA level outcomes 6 (Professional and technical communication) and 9 (Independent learning ability). Within the supervision of the project I facilitate ECSA outcomes 8 (Individual, team and multidisciplinary work), 10 (Engineering professionalism) and 11 (Engineering Management).

As part of the outcomes for the Mechanical and Aeronautical Engineering degree at the UP, students must gain 240 hours of industrial experience at the end of their 2nd (MPY315) and 3rd also EEC student are included in (MPY415/EPY420) years of study. The aim is to develop an insight in the practical application of engineering science in industry and the related human relationships and safety aspects. The Engineering Council of South Africa requires this type of experience in the training of engineering students. We recruit between 6-10 students here and have them trained at the Council of Scientific and Industrial Research (one of the main industry partner of UP) in composite design and manufacturing and airframe integration. After which each of these students are assigned to smaller design and manufacturing portions of the greater team. Figure 1 shows the specific structure of the University of Pretoria team (Smith et al., 2018).

Figure 1: University of Pretoria local team structure (Smith et al., 2018).
Graduate students volunteered and acted as interim project managers and advisors, but within this structure the main staff members were still involved at each level and with each design decision, to ensure success of the project and mentorship of the students from 2nd year to graduate level. In this way students would naturally gravitate towards a mentor and be supported in terms of design and manufacturing but also in professional skills (effective communication, conflict resolution, persuasion, organizational abilities and motivation of team members) not formally taught or assessed.

As an overall reflection of the success of this project and the management thereof, there were some aspects not considered with regard to an academic student based project. The most critical and disruptive of these challenges were the alignment of vision between teams and individuals. With each of these challenges the whole project had to be reviewed and adjusted to not strain the students with additional workload, but allow them to be part of discussions and decisions within these complex frameworks that exist in real-world projects but are never formally taught in the curriculum. This was a unique opportunity to give students a typical non-engineering challenge that regulatory bodies can bring into the design space and to best work with these restriction without compromising the final design objectives (Smith et al., 2018).

Results

In a true research or design scenario there are continual changes and challenges from different sources (client requirements, product viability, engineering method advances, manufacturing advances, etc.). The success of these projects lie as much in the students engineering skill and reasoning abilities as it does in the more professional skills like project, time and risk management and conflict resolution. These professional skills cannot be formally taught in a course with 250+ students as passive learning, but they are rather skills developed due to skilled and mature guidance from a mentor, to overcome difficulties encountered within these active learning project structures. At time this happens automatically, however this platform was used to guide the student without doing the personal development work for them but give them reasonable challenges to overcome and feel empowered within their own abilities.

As far as the formal assessment within the selected modules were concerned, there was a seamless integration with the existing structure, but a stark difference between students in the normal student body compared to students from the AREND group. A combination of the top-down and bottom-up mentorship the greater team members offered each other and the interaction with postgraduate students who are more mature designers and researchers, the students, especially the final year design and research students were significantly more confident and empowered to tackle their projects. Also with greater success compared to other students. Student reflections a year after they have graduated on the impact of taking part in AREND all indicate a greater ability to take on leadership and/or integrate into multi-disciplinary teams. They also reported a greater ability to self-regulate and effective execute project deadlines with time constraints.

Conclusions

It was clear from both the formal assessments and personal testimonials that multi-national, multi-disciplinary vertically integrated projects could be integrated into the existing curriculum structure at UP. Not only was this integration and the assessment of students within the
process a success, but the students were also benefitted by their involvement in this project. This experience allows for development of professional skills and for personal mentorship with staff and older students within a team framework that is invaluable for young engineers as they enter the workforce.

One caveat in the organization of a global project with independent local teams is that the project’s systems engineer has a more difficult job to understand the system engineering process developed by the individual teams. This was by far, the most important part to maintain within the structure developed. The main focus of the project system engineer is also to facilitate proper hand over documentation and collection of skill acquired to ensure ease of transition between student groups. Hand over documentation is also a valuable concept for students (who do not encounter this in any other formal course or project in the curriculum) to prepare them for industry engagements.

References


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The students worked incredible hard on the project and specifically the Stuttgart intern, Mr L Fels and Mr A Buysse from the Colorado team that used some of his holiday in South Africa at the end of 2017 to join the team for some tests.

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Mathematical competencies of a cohort of engineering students at a university of technology

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Context
This study presents a motivation for, and an analysis and interpretation of the data arising from, the diagnostic assessment of a cohort of engineering students at a South African university of technology. There are many studies dealing with the mathematical under-preparedness or otherwise of many first time entering university students in Engineering (NBTP (2015); Bohlmann, C.A., Prince, R.N. & Deacon, A. (2017). Klingbeil,N., Mercer,R., Rattan,K., Raymer,M., Reynolds,D. (2005); Spaull, N., & Taylor, S. (2015); (Crawford, Gordon, Nicholas & Prosser, 1998a; 1998b). Misalignment between their school mathematics and what is required in a first year university engineering mathematics course is often considered the core problem. This study adds to that body of research since it investigates the situation for university of technology students in a South African context, where the mathematical proficiency is often much lower than desired or expected.

Purpose
In order to make any intervention, we needed to understand what the mathematical proficiencies profile was of the incoming students. Based on that, we could then consider the potential impact as well as strategies to support the cohort. Our research questions were: What is the detailed breakdown of the mathematical competencies of a first year cohort of university of technology engineering students? What are the implications for the successful delivery of our programme?

Approach
The diagnostic tests used in the study were from the National Benchmark Test Project. The Tests assess mathematical competencies in post school applicants for tertiary study. Generalised mathematical competencies, that is algebraic processes, number sense, functions and graphs, concepts in trigonometry, transformations and spatial perceptions and geometric reasoning were the areas targeted for assessment.

Students wrote two three hour tests, one in Mathematics (NBT MAT) and one in Quantitative Literacy (NBT QL). The mathematics topics mirrored those done in the formal school setting, while the quantitative literacy questions were of a more generalised nature. Students were not allowed to use calculators, tablets or smart phones; they used paper and pencil.

Results
The researchers interpreted the data with regard to its impact on the current tertiary mathematics curriculum. The overall performance of the candidates on the NBT MAT test was worrying, with almost 81% of the writers placed in the basic category whilst only 0.57% fell into the proficient category. The writers in the engineering faculty performed poorly as expected with 73 percent in the basic category, 26 percent in the intermediate and over 1 percent in the proficient category (Figure 1).
An analysis of the profile of competencies for the cohort was done (see figure 2). Seventy five percent of writers performed below 45% in all competence areas with Geometric reasoning having the lowest performance amongst students.

(Figure 2 MAT subdomain scores in Engineering)

**Conclusion and Recommendations**

Findings arising from an analysis of the data indicate serious misalignment of competencies with what is required at the tertiary level. General strengths and weaknesses of both whole groups and individual candidates were clearly identified.

Implications for the university programme point towards curriculum intervention, including adaptations to pacing, streaming and teaching and assessment approaches. Mathematics remediation for engineering mathematics is not a new trend. All students in the engineering faculty can benefit from a mathematics intervention informed by the NBT data. Targeted technological intervention is also recommended.

Consideration should be given to alternative models for introducing an engineering curriculum to minimise the potential negative impact of starting off a poor mathematical platform. This approach has at least two clear benefits: the cohort court be inducted into engineering straights off without the constraints which a poor first level performance in mathematics often bring. Also it could make the space and time available to develop the competencies which are required for the use of higher mathematics in more senior courses in the meantime. See, for example, Klingbeil, N., et. al, (2005) for a discussion of just such a project.
References
NBTP national report: 2015 intake cycle .CETAP report number 1/2015, (CHED) University of Cape Town;

Acknowledgement
We are grateful to the Centre for Educational Testing for Access and Placement, UCT for the tests and analysis they provided.

Keywords
Diagnostic test; mathematical competencies; engineering mathematics intervention

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“Out of the Box” Low-Cost Portable Tinker Space for Elementary Engineering Education: A Classroom Resource - Pilot Study

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Abstract: Engineering education within the elementary classroom does not require an elaborate budget nor a large space to be effective. A low-cost portable Tinker Space could help elementary teachers include more engineering into their school day, eliminate the uncertainty of how and what to teach, and which tools and materials are appropriate for their classroom.

Introduction

When elementary students learn about engineering early on in their school career, they are exposed to opportunities in engineering, science and technical careers. Engineering in elementary school also encourage students who have the capacity, especially girls and minorities, to consider taking math and science classes in high school and lead to careers in engineering. When students engineer, they collaborate, think critically and creatively, and communicate with one another.

According to research done by the Museum of Science of Boston and the Engineering is Elementary project a well-designed engineering unit has 8 critical components. These design components support effective learning of engineering in elementary school. The critical components and design elements for the project must include: a narrative context; goals, constraints and requirements; engineering design processes practices; materials and methods; application of science and math principles; analysis for data planning; collaboration and agency (Engineering is Education, 2019).

The objectives of introducing materials and methods is to have students “explore, describe, compare, evaluate, and make arguments about the properties of materials for use in a design” (Engineering is Education, 2019). By guiding students with organized materials to use design challenges students will be able to compare, evaluate and make arguments about the best materials to use in their engineering projects. With Tinker Spaces meeting this critical component of effective engineering units, teachers will be able to focus on crafting a narrative and implementing the design process. This additional burden will be alleviated, and teachers will be more inclined to implementing engineering into their curriculum.

Research Question

The purpose of this research is to generate a low-cost portable Tinker Space that will facilitate student’s conceptual knowledge and skill application development of engineering principles within the elementary classroom and to provide practitioners (teachers) with a list of lesson plans, materials, and tools required to facilitate this learning. The following research question guided the analysis of this project:

1. What materials do practitioners (teachers) suggest are needed within a low-cost portable Tinker Space?
Methodology

The data collected for this research project will be a list of lesson plans, materials, and tools needed to facilitate the teaching of engineering within the elementary classroom. A survey to be delivered to 60 elementary school teachers in three countries (20 teachers from each country). The survey instrument will collect basic demographic information including grade taught, gender, and years of teaching experience along questions designed to support data collection for the research question toward identifying which common lesson plans, materials, and tools are used and which are desired but are not currently being used.

Survey and Pilot Study

A pilot study has been conducted with a survey instrument delivered to 20 elementary school teachers in two states. The survey aimed to discover what lesson plans, materials, and tools elementary teachers require and desire to facilitate a low-cost portable engineering lesson. The survey instrument collected demographic information such as Name, Grade Taught, Male/Female, and Years of Teaching Experience. The survey instrument questions were:

1. What materials do you use for engineering lessons?
2. What tools do you use for engineering lessons?
3. What engineering lesson plans do you use?
4. What low cost material would you like to use that you have not listed?

Note: In addition to the pilot study, survey distribution, data collection, and data analysis will be performed within three months following REES2019. The author seeks collaborators for this project from two countries outside of the United States of America. Contact information is within the author details sections of this paper.

Data from the pilot study will be made available for collaborators to review and used to develop the survey instrument further.

References


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Assessment “as learning” in an extended engineering degree programme: implementing iPeer LMS feature to evaluate peer participation in teamwork

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Abstract: A skills and practices-based module presented in the first year of an extended 5-year engineering degree programme at the University of Pretoria (UP) uses teamwork on projects as initial introduction to ECSA Exit level outcome 8. The iPeer tool for formative assessment of teamwork participation, was implemented in the module in 2018 to facilitate the use of real-time assessment for team members to identify individual patterns of underperformance. The fit for purpose of the tool for entry-level students was questioned. As a project-in-progress qualitative and quantitative data were analysed for the purpose of informing best practice. Students gave positive feedback on the usability of iPeer and individual student learning. Analysis indicated that (1) improvement in individual behaviour is viable; (2) comments are extensive and honest; (3) for entry-level students additional training to provide constructive and reciprocal feedback needs more attention.

Context
A skills and practices-based module, Professional Orientation (JPO120) presented in the first year of an extended 5-year engineering degree programme (ENGAGE) at the UP uses teamwork on projects as an initial introduction to ECSA Exit level outcome 8.

In support of UP’s move to a hybrid approach to learning the iPeer tool for formative assessment of teamwork participation was implemented for the first time in 2018 to facilitate the use of real-time assessment for student team members. It was anticipated that the tool would assist team members to identify individual patterns of underperformance. Prompt feedback in iPeer is focused on clearly defined behaviours, and could potentially lead to improved individual participation and engagement.

The current project forms part of a larger research project in the UP EBIT Faculty in which the iPeer tool, a building block in the official LMS at UP, is also used with third and final year modules.

Purpose
In the current research project-in-progress, the iPeer tool is used for monitoring assessment “as learning”, already proven to be implemented successfully in other participating EBIT modules. The fit for purpose of the tool for younger, entry-level students is however still in question. Therefore, we wanted to determine: (1) if students at the entry-level of an engineering degree could effectively use iPeer as a tool for real-time assessment “as learning” to improve their own individual participation as a member in a team; and (2) to determine the usability of iPeer as an online tool for assessment and student learning for under-prepared ENGAGE students.
Approach

In JPO120 workshops are facilitated during the course of the first semester to provide both theoretical knowledge and practice on different components of teamwork. Focus is placed on effective communication strategies, handling of conflict in team work, learning style preferences and its role in collaborative teamwork activities, and effective time management to enhance student participation within teams. At strategic points in the semester students are also instructed and assessed on the use of individual self-reflection.

Following in the second semester, the Go Green project employs one iPeer assessment (iPA) opportunity per CDIO stage (Conceive-Design-Implement-Operate). During the Conceive stage, iPA-1 focuses on assessment of team members' participation and contribution during an initial brainstorming session on the selected topic. iPA-2 in the Design stage provides an opportunity for mutual feedback on team members' contribution to the team's research report. During the Implement stage iPA-3 provides opportunity for reciprocal feedback on individual team members' participation and contribution to the teams' joint PowerPoint presentation. Using this, each team finally gives oral feedback in the Operate stage on successes and challenges of the executed project and also future recommendations. The assessment of the project concludes with a final iPA-4 assessment with a reflection and feedback of each team member's overall participation and contribution to the team.

Administering iPA-1 to iPA-4

The iPA-1 and iPA-4 were compared to gage improvement in team member’s participation and contribution. iPA-1 was guided by rubric criteria with compulsory comments and a self-evaluation. In iPA-4, a "simple evaluation" in which a total of 40 marks has to be divided between the 4 team members, also required a final comment on the participation and contribution to the project as a whole.

Selection of students for qualitative comparison

Based on the results of the assessments as described above, five students were selected to explore possible improvement in both participation, engagement and contribution in their teams. They were selected from the five most underperforming teams according to iPeer criteria assessed in iPA-1. These students’ average mark for iPA-1 was significantly lower than the team average mark. A qualitative comparison of team members’ comments for these five students (iPA-1 versus iPA-4) was made to identify improvement/lack of improvement, of these students.

Anonymous student feedback survey (Qualtrics)

At the end of the project all participating students were requested to complete a Qualtrics survey to provide feedback on two aspects, namely the usability of the iPeer tool, and the impact of iPeer and team work on student learning, career and future employment. The usability includes level of difficulty in using, navigation and overall impression of iPeer. Student learning includes students’ perceptions on the fairness of the tool, the effect on final grades, level of comfort of being assessed, utilisation of comments and feedback, and the impact if iPeer on team work skills.

Pedagogical underpinnings

The iPeer Go Green project is informed by (1) the guiding principles of real-time student assessment and related processes (Maki, 2017); (2) the Mind- Brain- and Education (MBE) principles; and the CDIO initiative as an innovative educational framework which aims to produce the next generation of engineers and implemented in JPO120 for the past 8 years.
Results

Both qualitative (Qualtrics survey results) and quantitative (iPeer assessment marks and comments) data were analysed for the purpose of informing best practice. Qualtrics data were coded and analysed using AtlasTi (Saldana, 2016) to explore related themes and sub-themes that was derived from feedback such as the following:

“You only know yourself based on how you see yourself. iPeer allowed me to see myself through other people and what they thought of me and the positive and negative traits I have. It allowed me see what I am doing right and how to improve on the stuff that I am doing wrong.”

“I saw the ipeer experience as a simulation of a scenario I will have in the workplace someday where I will be working together with other engineers and will have to make judgements based on their contribution rather than friendship because of our work being very serious.”

“I assessed all my team members honestly at all times, because that is the only way in which they could learn and improve their teamwork skills. I would have appreciated it if I was assessed in more detail by my team members.”

Approximately a third of 100 students completed the Qualtrics survey using a five point Likert scale. The results are illustrated in Figure 1.

<table>
<thead>
<tr>
<th>Student Feedback (Usability of iPeer)</th>
<th>Somewhat easy</th>
<th>Very easy</th>
</tr>
</thead>
<tbody>
<tr>
<td>I needed instructions in order to use iPeer</td>
<td>17.86%</td>
<td>62.14%</td>
</tr>
<tr>
<td>Overall usability of iPeer</td>
<td>46.43%</td>
<td>50.0%</td>
</tr>
<tr>
<td>Student Feedback (Student Learning)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Can team members be assessed fairly?</td>
<td>15.38%</td>
<td>84.62%</td>
</tr>
<tr>
<td>Is the final grade a fair reflection of the individual effort by using iPeer?</td>
<td>30.77%</td>
<td>69.23%</td>
</tr>
<tr>
<td>Did you feel comfortable assessing the other team members?</td>
<td>11.54%</td>
<td>88.46%</td>
</tr>
<tr>
<td>Did you feel comfortable being assessed by the other team members?</td>
<td>7.69%</td>
<td>92.31%</td>
</tr>
<tr>
<td>Did you feel comfortable evaluating your own contribution?</td>
<td>15.38%</td>
<td>84.62%</td>
</tr>
<tr>
<td>Have you read the iPeer comments that you received from your team members?</td>
<td>11.54%</td>
<td>88.46%</td>
</tr>
<tr>
<td>Do you think iPeer will have an impact on teamwork skills?</td>
<td>7.69%</td>
<td>92.31%</td>
</tr>
<tr>
<td>Do you think the teamwork skills are valuable for your future employment and career?</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Do you think using iPeer was a valuable experience for you?</td>
<td>7.69%</td>
<td>92.31%</td>
</tr>
</tbody>
</table>

Figure 1: Example of positive student feedback on the usability of iPeer and individual student learning

The iPeer data identified active student participation in three of the four iPA opportunities. The participation in iPA-2 went down from 131 in iPA-1 to 73 participating students. Penalties were activated for iPA-3 and iPA-4, and significant improvement was shown with only 4 of 136 students not participating.

It is possible to track individual student improvement in iPeer. The analysis of all 136 students’ comments led to three observations: (1) improvement in individual behaviour is viable; (2) comments are extensive and honest; (3) for entry-level students additional training in providing constructive and reciprocal feedback needs more attention. Figure 2 illustrates the extent of feedback the students provided to each other. Especially for entry-level students, the depth and quality of the comments are noticeable.
Conclusions

The effective use of an online assessment tool for teamwork with entry-level students had been questioned. After one year of use, buy-in from the students and limited highlighted concerns were observed. The vision for implementing iPeer for assessment “as learning” to foster changed behaviour, self-regulated learning and metacognition appears achievable. This research will continue in 2019 and 2020 to inform practice in the JPO120 module, and to contribute to the larger EBIT Faculty iPeer project.

References


Enhancing Elementary Engineering Education with Stop-Motion Animation: An International Collaboration Project

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Abstract: The delivery of engineering content within the elementary classroom is often met with confusion and resistance. Historically, elementary classroom teachers were not required to take engineering courses while attending university nor did they receive any professional development regarding the implementation of engineering principles within their current curricular content. This research project aims to provide practitioner (teacher) insight regarding the use of stop-motion animation as a platform to deliver engineering education within the elementary classroom through transdisciplinary learning opportunities that focus on a digital media literacy pedagogical approach.

Introduction

Transdisciplinary learning refers to concepts “between the disciplines, across the disciplines, and beyond all disciplines” (Nicolescu, 2002, p. 44). It helps prepare students for success in the 21st century; it builds on Erickson’s (2007) enduring understanding. Research shows that, regardless of demographics, students are challenged and motivated to “think and make decisions in collaboration with others, using and valuing the expertise of peers” (La Porte, 2017, p. 467). These skills are important for 21st century learning as they, when combined with technological literacy, will serve as the foundation for workplace readiness in our global society (Dugger, 2007).

Students today live in a digital world of videos, games, social media, and photos both online and on mobile devices. This surge of media brings a focus to digital media literacy that focuses on the ability to access, analyze, or produce media messages in non-written modes via media communication technologies (Dezuanni, 2015) and is recognized as an essential competency for living in the new media age (Jenson, Dahya, & Fisher, 2014). Sun, Wang, & Liku, 2017 suggest that media production allows students to be more effective media analysts, promotes social and cultural participation, and could permit a sense of satisfaction from engaging in the production of their digital work. Stop-motion films are a simple method that allows students to engage in media production that has demonstrated the ability to support learning in various concepts (Vratulis, Clarke, Hoban, & Erickson, 2011; Hoban & Nielsen, 2014; Lee, 2015).

Stop motion animation films are created by putting still images together in a video clip that is played at a slow frame rate where the creator can stop, discuss, and think about their information for each photograph (Fleer & Hoban, 2012; Lee, 2015). Stop motion animation provides a platform for students to collaborate and discuss concepts toward furthering understanding and mastery of concepts which enhance the learning experience (Hoban & Neilson, 2014). The International Society for Technology in Education (ISTE) featured an article titled Engage Elementary Students with Stop Animation! (Hatten, 2019) outlining several benefits for students while using stop motion animation as a platform to explore new content including capturing the imagination, investment, and memory of the students. With stop motion animation, students are forced to slow down, become intentional regarding next steps, and practice a structured approach to explaining complex concepts. This is ideal for guiding students through content areas where processes and progression are involved (ISTE, 2019).
Research Questions
The purpose of this research is to gauge current practitioner interest of teaching engineering concepts using stop-motion animation as a medium within the elementary classroom. The following research questions will guide the analysis of this project:

1. How comfortable are elementary teachers with teaching engineering concepts?
2. How comfortable are elementary teachers with using stop motion animation?
3. How interested are elementary teachers with using stop motion animation to teach engineering concepts?

Methodology and Research Overview
A survey to be delivered to 60 elementary school teachers in three countries (20 teachers from each country) aiming to identify practitioner interest in using stop-motion animation as the medium to teach engineering education within the elementary classroom. The survey instrument will collect basic demographic information including grade taught, gender, and years of teaching experience along questions designed to support data collection for the research questions.

<table>
<thead>
<tr>
<th>Table 1. Comfort &amp; Interest by Years Teaching</th>
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</thead>
<tbody>
<tr>
<td>Years of Teaching Experience</td>
</tr>
<tr>
<td>0-3</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>Comfort teaching engineering</td>
</tr>
<tr>
<td>Comfort using stop-motion animation</td>
</tr>
<tr>
<td>Interest in teaching engineering concepts</td>
</tr>
<tr>
<td>using stop-motion animation</td>
</tr>
</tbody>
</table>

Note: The survey instrument has been developed in an electronic format. Survey distribution, data collection, and data analysis will be performed within three months following REES2019. The author seeks collaborators for this project from two countries outside of the United States of America. Contact information is within the author details sections of this paper.

References


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Adoption of Computational Modelling in Introductory Engineering Course Modules: A Case Study

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Abstract
This study seeks to explain the adoption and use of computational modelling and simulation across introductory engineering modules following the advent of the Integrated Engineering Programme (IEP) curriculum framework in 2013. Rogers’ (2003) diffusion of innovations theory served as the theoretical framework for this study. Findings from the study suggest that there is a correlation between academics’ views and perceptions of active learning methods and their adoption of computational tools in their teaching. In addition, the study also suggests that the adoption of computational tools at both individual and departmental level bears some correlation to their perception of, and commitment to the values espoused by the IEP.

Introduction
The objective of the study reported here is to analyse the extent and pattern of adoption of MATLAB and other computational tools within introductory engineering modules at University College London (UCL). The study also seeks to identify whether the adoption of computational tools within engineering teaching bears any relationship to the introduction of the Integrated Engineering Programme (IEP) curriculum framework in the Faculty of Engineering Sciences in 2013 (Mitchell et al., 2019). The IEP specifically led to the introduction of computational modelling within first and second year engineering mathematics modules. Hence, the main assumption underpinning this study is that the inclusion of MATLAB tuition within engineering mathematics teaching in 2013 served as a catalyst for the adoption of computational modelling as a teaching tool in introductory engineering modules.

Context and assumptions underpinning this study
Prior to 2013, the department of mathematics was responsible for delivering mathematics tuition on behalf of the majority of engineering disciplines within the Faculty of Engineering Sciences. However, in 2013 mathematics tuition was brought in-house was to ensure that students would study mathematics within the context of engineering (Nyamapfene, 2016). Since then, MATLAB has been used as a mathematical modelling tool to reinforce the connection between engineering mathematics and the fundamental concepts underpinning their studies in the engineering disciplines. The teaching and use of MATLAB within engineering mathematics teaching has enabled students to use MATLAB graphics and visualisation features to gain a physical understanding of the basic mathematical concepts and equations that underpin the study of engineering. In so doing, it has enabled students to use their mathematical knowledge to explore the basic engineering principles underpinning the various engineering disciplines taught at UCL without being bogged down by tedious mathematical calculations and computations.

The inclusion of MATLAB tuition within the engineering mathematics modules has helped to equip students with the basic MATLAB skills needed for computational modelling and simulation in other engineering modules. In addition, MATLAB is widely used by engineering academics within the faculty in their research. Consequently, the integration of MATLAB tuition within the engineering mathematics modules ensures that MATLAB is a tool that both academics and students are familiar with.
Research design

Prior to this study there was already some evidence that following the decision to integrate MATLAB with first and second year engineering mathematics, there has been a corresponding increase in the use of MATLAB and other computational tools in introductory engineering modules. This study sought to establish whether or not this relationship is causal. Moreover, the adoption of MATLAB across the engineering disciplines has not been uniform, and hence one objective of this study is to establish the reasons for this variability. To this end, I sought to establish individual academics’ motivations for adopting computational modelling in their modules. I also investigated whether or not there were any departmental factors that had an influence on academics’ decisions to adopt MATLAB, or any other computational tool, as a teaching tool within the early-stage foundational engineering course modules. As part of this study, I also investigated the extent to which the introduction of MATLAB and/or other computational tools has affected the structure of learning and assessment activities within modules.

To guide this study, I chose the following research questions to frame the study:

RQ 1 What has motivated academics to adopt computational modelling within introductory engineering modules?

RQ 2 How has the introduction of computational modelling affected teaching and assessment within the modules that have adopted it?

RQ 3 What are the departmental characteristics that correlate with increased adoption of computational modelling within introductory engineering modules?

Method

To address these research questions, I adopted a qualitative case study approach that incorporated interviews with academics across five engineering departments in the Faculty of Engineering Sciences at UCL who had adopted MATLAB and/or other computational tools in their teaching in first and second year engineering modules. I used Roger’s diffusion theory of innovation (Rogers, 2010) as the theoretical framework to guide me in specifying the research questions, methodology and data analysis techniques that I utilised in this study.

According to Rogers, diffusion “is the process by which an innovation is communicated through certain channels over time among the members of a social system.” Rogers also identified five innovation attributes that predict the innovation’s rate of adoption by an individual or group of individuals. These attributes are relative advantage, compatibility, complexity, trialability and observability. Using this as a basis, and with reference to guidance for formulating innovation diffusion questionnaires from Atkinson (2007) and Sonnenwald et al. (2001), I came up with a series of interview questions for the study.

To identify the participants for this study, I went through all the module descriptions for first and second year undergraduate engineering modules in the Faculty of Engineering Sciences and identified all those modules that explicitly made reference to any one of the following terms: MATLAB, computational modelling, computational simulation, or that made references to specific computational software other than MATLAB. From this set of modules, I identified and retained engineering principles modules that made specific reference to MATLAB or any one of the computational tools in their descriptor. For example, I retained modules such as “Introduction to Thermodynamics” as long as they made reference to some computational tool in their module descriptor. However, I removed from the list any modules whose main focus was the introduction of one or more computational tools. For example, I removed from the list modules such as “Introduction to Programming” and “Computational Tools for Chemical Engineering.”
Study Findings

A key outcome of this study was that academics who adopted computational tools as teaching aids in their introductory modules in engineering tended to have had more involvement in the conceptualisation, design and implementation of the Integrated Engineering Programme than those who did not. Specifically, those academics who taught on the engineering mathematics modules also tended to have replicated the use of MATLAB or other equivalent computational tools on their other modules. In addition, they were also more likely to be involved in, or to have attended a number of teaching and learning seminars hosted by the faculty or by the UCL Arena Centre for Research-based Education, which is responsible for academic staff development. Adopters were also more likely to state that they had adopted computational tools in their teaching as this was consistent with their views and philosophies of teaching. All these features are consistent with the descriptions for early adopters of innovation as discussed by Rogers (2010).

Those who adopted computational tools in their teaching were also more likely to have simultaneously adopted one or more forms of student-centred, active learning methods in their teaching as well. Reasons given for this were that computational modelling went hand in hand with active learning. In addition, these adopters also tended to use collaborative group work in their teaching and assessment practices. In addition, whilst the traditional engineering module tends to be assessed more or less exclusively by the closed book end of module exam, modules run by adopters tended to have significant amounts of both formative and summative assessment. Again, these practices are consistent with the IEP ethos.

The study also found some correlation between departmental commitment to the values of the IEP and their adoption of computational tools in their teaching. Departments committed to the IEP ethos also tended to have a larger number of modules utilising computational tools in their teaching. Additionally, such departments tended to have organisational structures that supported the introduction of such tools. For instance, such departments tended to run generic computational modelling course modules to enhance the computational skills of their students. They also tended to have dedicated teams of PhD students to support students in the use of MATLAB and other computational tools deemed essential to their discipline.

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Using a diagnostic test to inform and improve teaching for first year engineering students

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Abstract: A diagnostic test was designed to identify gaps in first year engineering student knowledge and skills, with the aim of improving teaching in first year modules. The test was developed by a team of engineering lecturers to test a range of mathematical and cognitive skills. The pilot test shows promise as a diagnostic tool, and now needs to be validated.

Context
Pass rates in some first-year engineering modules at the University of Pretoria (UP) are low. Admission to the university requires high achievement in high school Mathematics and Physical Science [1],[2],[3], however, these results are not a reliable predictor of success in the first year. Lecturers in first-year modules claim students do not succeed because they lack mathematical skills, as well as critical thinking, reasoning and problem solving competencies. In this context, a project was initiated to design a diagnostic test (DT) which would identify gaps in student knowledge and skills, and allow appropriate interventions to close these gaps.

Purpose
The aim of this research is to investigate the ways in which the first year engineering diagnostic test can be used to inform and improve teaching in first year modules at UP.
Approach

In a series of workshops, a team of experts from various engineering disciplines in collaboration with their education consultant, established a set of core knowledge areas and competencies which they regarded as important for an entering first-year engineering student. The team developed a DT with questions addressing each of the identified critical competencies. The DT is designed to be given to first year students with no prior preparation. Before testing, focus groups were held with the lecturers of first year modules to validate which areas they believe are critical for their particular module. The collective student performance on these areas will then be shared with the lecturers to allow teaching in these modules to be better aligned with student needs.

The development of the DT was funded and a comprehensive 30 page project report was submitted at the end of 2018. Aspects covered in the report were: the design process; implementation and tools utilised; selection of students for the pilot; assessment, outcome data analysis and comparison; lessons learnt with reference to the scaling up of DT, redesign, designing interventions and stronger statistics. In addition, the initial question set and validation evidence as well as the administered question set was submitted with the report.

Results

The diagnostic test of 30 test items, designed in alignment with Bloom’s Taxonomy, was piloted in 2018 with a small group of students. A slightly revised test consisting of 25 test items was written by all first year engineering students at the start of the 2019 academic year.

The 25 items in the test were categorised in multiple dimensions. Five questions were characterised as testing knowledge, while twenty tested application. On the Knowledge dimension, 1 question was identified as Factual, 15 as Procedural, 8 as Conceptual and 1 as Metacognitive. On the Cognitive process dimension, the questions were divided as follows: 2 Understand, 9 Apply, 8 Analyse and 6 Evaluate.

The items were further categorised according to skills tested. The nature of skills were categorised as mathematical skills as well as other cognitive skills needed to understand and solve the problems. A specific item could include more than one skill in more than one category.

The mathematical skills included:
- Manipulation of equations – including fractions, ratios
- Understanding and manipulation of inequalities
- Graphs
- Mathematical language and correct use of notation
- Calculations - multiple step procedures and applying geometric formulas
- Trigonometry
- Geometry
- Differentiation

The other cognitive skills included:
- Reading comprehension: Reading, understanding and interpreting instructions
- Contextual problems: Mathematical modelling, translating a contextual scenario into a mathematical problem
- Logical thinking
- Estimation
- Visualisation

The understanding and use of vectors was identified as a skill introduced in physical science.
The pilot test showed promise as a diagnostic tool. The test correlated better with performance in first year modules than high school exam or standardised test results. Engineering Aptitude Tests are not an unknown phenomena and homegrown tests seems promising, but the tests are of little value if not validated [2]. Therefore, the next step is now to evaluate the validity of the DT. A pilot focus group with lecturers in one chosen module was conducted before the start of the academic year. The responses of the lecturers to the test items were recorded. In a follow-up interview lecturers will be requested to respond to the test results, and the potential to improve teaching in the module based on the results will be captured.

Conclusion
We expect to identify areas where there is a gap between the student profile and lecturer expectations, and to interrogate the possibilities for improving teaching in these areas. We also expect to identify areas where questions should be refined, or added to the test. During the second part of 2019 the DT will be evaluated for validity and reliability by a specialist in this field.

References
Engineering self-efficacy in former “street youth” in a residential school in Kenya: A case study

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Introduction and Context

UNICEF estimates that 300,000 “street youth” live in Kenya (IRIN, 2007). “Street youth” or “street children” is a broad term used by UNICEF to refer to children connected to the street either through living or working on the street. As acknowledged by UNICEF’s report, “street youth” is problematic but replacement terms are often unwieldy (Steffen, 2012). This paper, also, recognizes the problematic nature of grouping this diverse population. Some stay on the streets only during the day, while a majority live on the streets full time. The top reasons for leaving home include socio-economic factors, poverty, and lack of family care. For education, a majority have attended formal school at some point and hope to return to school (Sorber et al., 2014). To deal with these educational needs, the Tumaini Centre opened in 2009 with the goal of offering educational opportunities in a safe environment to a group of former “street youth”.

Since then, Tumaini has evolved into the Tumaini Innovation Centre, an alternative residential school in Eldoret, Kenya for a small population of former “street youth”. Tumaini offers rehabilitation, food, board, and education to its students. The centre seeks to support and prepare its students for their future by providing accelerated, skill-based education for primary and vocational students. Its vocational school offers programs in mechanics, electronics, welding, and hairdressing. Three years ago, a partnership began between the centre and engineering education researchers in the USA. Through this partnership, Tumaini offers a course that teaches engineering skills and problem-solving contextualized around local needs (D. B. Radhakrishnan & DeBoer, 2016).

This collaboration evolved to focus on the growth of Tumaini instructors, as prior work identified them as the key to successful implementation of the engineering program (D. Radhakrishnan, Capobianco, & DeBoer, 2018). As such, significant research has been done to examine their teaching methods and attitudes. Improvements due to this research have resulted in sustained growth in effective teaching practices through critically reflective practice among the teachers participating (D. Radhakrishnan et al., 2018). Teachers and researchers anecdotally observed growth in understanding of engineering, engineering self-efficacy, and engineering self-concept. Of these three areas, this research initially focuses on self-efficacy to align with Tumaini’s goals. As Tumaini seeks to expand, research on the students’ growth in self-efficacy will help with the continuous alignment with the course to students’ needs.
Self-Efficacy

Across both fields and age ranges, many studies examine growth through academic achievement (Kremer, Flower, Huang, & Vaughn, 2016; Stevens & Schulte, 2018; Warne, 2014). However, this study seeks to look at the attitudinal constructs that mediate student achievement and opportunity to learn. We therefore examine student growth in engineering self-efficacy. Self-efficacy is the perception each student has about their abilities within a specific context. High self-efficacy has been shown to lead to greater persistence and achievement (Schunk & Pajares, 2002). Self-efficacy beliefs are multifaceted and contextual (Pajares, 1997). Yet, these beliefs are often measured through quantitative methods often using Likert scale questions. Yet, this approach leaves a large gap in knowledge. What does the student think is required to do well in that job/major? What specific skills do they think they lack and what skills do they feel they have? Responses to these questions may come from qualitative methods that provide a more nuanced view of self-efficacy.

Most qualitative research in self-efficacy relies on the precedents set by quantitative research. Hutchison, et. al. (2006) used a combination of qualitative and quantitative research to examine self-efficacy beliefs for first-year engineering students. Their data collection involved Likert scale items to rank their self-efficacy beliefs and then areas to list factors they felt influenced these beliefs. Students then ranked the impact of these factors on their beliefs (Hutchison, Follman, Sumpter, & Bodner, 2006). However, this approach still lacks nuance as to why students feel these factors influenced their beliefs. Additionally, since this study is done specifically on student’s self-efficacy within this class, it does not examine students overall engineering self-efficacy.

A more common route to conduct qualitative research on self-efficacy involves adapting qualitative questions from self-efficacy surveys and questionnaires. Zeldin & Pajares (2000) used this procedure to gather data to conduct a case study of STEM women. Questions from the interviews were framed based on questions from questionnaires that were made into open-ended questions in a semi-structured interview protocol. Students were prompted to reflect on the development of their self-efficacy. Similar to the adapted framework used in this paper, Zeldin & Pajares (2000) combined vicarious experiences and verbal persuasions into one category that formed one of two main themes contributing the self-efficacy of women in STEM (Zeldin & Pajares, 2000). A final method used to conduct qualitative self-efficacy research is creating a completely unique interview protocol based on Bandura’s (1977) self-efficacy framework (Usher, 2009). This paper will use the use the second method presented, which involves adapting questionnaires to create an interview protocol. This choice will both situate this paper in the larger body of both qualitative and quantitative research (which is challenging to do within the third method) and gain additional nuance for engineering self-efficacy beliefs (which is challenging to do within the first method).

Research Questions

This work-in-progress paper focuses on understanding engineering self-efficacy, the belief that one can perform tasks related to engineering, as students go through a multi-year engineering curriculum. This is a part of a larger research project examining the interplay between three ideas: self-efficacy, understandings of engineering (a student’s belief about what engineering is), and engineering self-concept (a student’s belief about themself as an engineer).

This research will examine the following questions (1) What are the current engineering self-efficacy beliefs of Tumaini students? (2) How do the Tumaini students describe changes in their own engineering self-efficacy beliefs?
Data Collection and Analysis

This work-in-progress examines self-efficacy beliefs using both what skills students view as important to engineering and which of these skills they feel they possess or are building. To gather such rich data, this study elicited students' descriptions of engineering self-efficacy through a semi-structured interview protocol. This interview was conducted with a total of 11 students, 6 from Tumaini's primary school and 5 from Tumaini's vocational school. The vocational students interviewed had taken the engineering course during their primary school experience at Tumaini. This protocol examined self-efficacy, self-concept, and understandings of engineering.

This interview data will be analysed using thematic analysis and then combined with data sources gathered throughout the three-year relationship with the Tumaini Innovation Centre including 18 student interviews and 3 years' worth of artefacts generated from classroom activities, observation videos, and assessments. Thematic analysis involves researchers familiarizing themselves with the data, creating initial codes, reviewing these codes and creating themes, and finally revisiting the codes to create final definitions for each code (Braun & Clarke, 2006). This data will be combined with other artefacts to create a case study of the engineering self-efficacy beliefs at Tumaini Innovation Centre. Case study provides a nuanced view of a well-defined single case. This final case study will be member check to confirm that the findings fit (Birt, Scott, Cavers, Campbell, & Walter, 2016; Cho & Trent, 2006).

Future Directions

Currently, this research is at the step of creating initial codes within thematic analysis through open coding. We have not yet started axial coding. No formal themes are available yet to present as findings. We therefore present our process, method, and initial findings.

This work-in-progress is part of a larger research study focused on the interplay between self-efficacy, self-concept, and understandings of engineering through the data collected from the interviews examined in this paper. As a part of this work, a framework will be developed to describe this interplay and define the influences at work in shaping the students’ understandings of engineering and how they relate to engineering. This framework will expand upon Bandura’s (1977) initial framework for self-efficacy. Our future work will frame the development of engineering self-concept and self-efficacy through the development of a social understanding of engineering. This work hopes to provide a conversation on how engineering identities are developed within a specific context and what part engineering education can play in this development.

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Developing growth mindsets to prevent dropout in engineering students at the University of Cape Town

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Introduction

Each year, about 15% of engineering students fail in their first year at South African universities despite high academic achievement at school (Department of Higher Education and Training, 2019). Some of these students can say what actions they should take to improve their academic achievement at university (e.g. attend class, ask for help, work in a study group) and yet they fail to implement these actions. Dweck’s (2006/2017) theory of growth and fixed mindset offers an explanation to this phenomenon. Students with fixed mindsets believe that academic ability is predominantly intrinsic and cannot be changed beyond a basic level. Fixed mindsets may have been reinforced in students with a history of low effort yet high achievement at school. When faced with a failed test at university, a fixed mindset student may think that they do not belong at university, or they may disregard the assessment, believing that the poor result is not a true reflection of themselves. Such beliefs may result in missed opportunities for improvement and a greater chance of further poor results due to not acting on feedback and not learning from mistakes.

In contrast, students with growth mindsets believe that academic ability can always be developed and that academic activities are for developing academic ability rather than showcasing ability. Since beliefs strongly influence behaviour (Multon, Brown & Lent, 1991), developing growth mindset beliefs may help students to implement the academic behaviour that is likely to lead them to greater academic success, such as trying different strategies to make progress, reviewing errors, and being inspired rather than being threatened by the success of others.

Research question

A systematic literature review of interventions designed to develop growth mindsets in engineering students (Campbell, Direito & Mokhithi, in press) had three main findings. First, interventions only showed small changes in students’ mindsets, as many engineering students already have growth mindsets. Second, an increase in growth mindset had at best a small correlation with an increase in course grades over six to twelve months. Third, the most commonly used intervention was teaching students about mindsets through readings, lectures or videos and then requiring students to reflect on what they learnt in discussions, reflective writing or writing advice for other students. Since all the interventions found in journal articles and conference proceedings came from the United States of America and the United Kingdom, we do not know if growth mindset interventions would have the same effects with South African engineering students.

The questions addressed in this work-in-progress paper are:

1. To what extent did the mindsets of first-year engineering students at a South African university shift towards strong growth mindsets following an intervention to develop growth mindsets?
2. Was there an observed increase in academically beneficial behaviour, such as asking questions, in students with stronger growth mindsets?

This study is important to engineering education in South Africa because large-scale studies (Sisk, Burgoyne, Sun, Butler & Macnamara, 2018; Claro, Paunesku & Dweck, 2014) showed that growth mindset interventions are most beneficial to students from lower socio-economic
backgrounds and minority students. At the South African university where this intervention takes place, graduation rates still reflect the apartheid legacy of differentiated education quality at schools along racial lines. Interventions that are effective with the students most at risk of not graduating in minimum time will help to improve overall graduation rates and work towards the broader aims of education to transform society.

**Methodology**

In the intervention, first-year engineering students will be introduced to the concept of growth mindsets in a face-to-face mathematics class in 2019 (n = 116 students) and sent links to two short videos in which Carol Dweck explains the researched benefits of having a growth mindset. Students who choose to participate in the research will be asked to make a short video or voice note to be shared with future first-year engineering students explaining why a growth mindset can benefit them. Following a mixed methods approach, a personalized, mathematics-specific version of Dweck’s 8-item Mindset Scales (De Castello & Byrne, 2015) with a 6-point Likert scale for responses will be administered to participating first-year engineering students before and after the intervention. Students’ question-asking behaviour in the mathematics course, in class and online, will be observed one week before and one week after the intervention. A purposive sample of students with different mindset ratings according to the Mindset Scale will be interviewed. Interviews will be analysed using NVivo software for evidence of fixed or growth mindset beliefs according to mindset characteristics. Interview data will be compared to students’ Mindset Scale responses, allowing for triangulation of mindset evaluations.

**Results**

This is a work-in-progress paper. It is anticipated that, after observing students for one week before and after the intervention,

1. a small, positive shift towards a strong growth mindset will be observed after the intervention,

2. the shift towards a strong growth mindset will be greater with students who initially have a fixed mindset,

3. students with stronger growth mindsets will be observed asking more questions in classes, online and/or in consultations with lecturers and tutors.

**Conclusions**

This research will contribute to the small set of existing research on interventions to develop growth mindsets in engineering students by adding results from a university outside the United States of America and the United Kingdom. While engineering students may start their degrees with growth mindsets (Frary, 2018), previous studies have observed a shift towards fixed mindsets during their first year, especially for students studying computer science (Flanigan, Peteranetz, Shell, & Soh, 2017; Reid & Ferguson, 2014). Therefore, an intervention that maintains an existing mindset may be counteracting a shift towards a fixed mindset. Further studies on the changes in mindsets of South African students over their first year are needed to be able to make meaningful interpretations about the observed changes in mindsets in this study.

This research is one step towards using the theory of growth mindsets to address the problem of why initially high achieving students fail to graduate with an engineering degree. However, further research is needed to assess whether once-off growth mindset interventions in first-year engineering courses are a significant way to address low graduation rates in engineering. Longitudinal, multi-year research is needed to determine how engineering students’ mindsets may shift as they progress through their degrees.
Campbell, Craig and Collier-Reed (2019) showed that both growth and fixed mindsets can be encouraged from the same learning theory and recommended that communication with students should be designed not to inadvertently encourage fixed mindsets. The effects of the learning environment on students’ mindsets, including how fixed mindset messages from one course may impact students’ mindsets and performance in other courses, is another area for further research.

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Keywords
growth mindsets, behaviour, beliefs, Dweck, learning, graduation rates

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The potential of utilising alternate capital in learning communities for managing alienation

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Introduction
This extended abstract stems from a study for a PhD research project that endeavored to understand student learning in an extended engineering program in order to enhance the experience and success of students. This paper reports on the part of the study that explored how students experience learning events as they transition from the extended program into the mainstream curriculum.

Context
Low throughput rates is not a new concern in tertiary education in South Africa. In the 1930s, South Africa's Minister of Education commissioned a study into high failure rates at the few elite Higher Education institutions. This study identified the transition from school to university as one reason and another was the inadequacy of the teaching system (Malherbe, 1965). In the 1950s, Apartheid laws and policy, incentivized and promoted white male access to and success in education. Hence, South Africa has a legacy, influenced by colonisation and apartheid, of an unequal education system. Economic and social disparities perpetuate inequality that students experience today. Compounded with this is the need for greater participation in higher education and equality of access to tertiary institutions. As a result, there are large classes in programs such as engineering at universities, with diverse classes of students, in terms of their abilities, learning styles, language skills and prior knowledge. Many students struggle to adapt to university for social and academic reasons. Many identify the pace of teaching and the workload as difficult in addition to the need to adapt to institutional practices and discourses.

This extended abstract introduces the study that investigated students’ experiences of learning as they transition from the extended degree program into the mainstream engineering curriculum at a South African university. At the institution of this study, the engineering extended degree students complete two years of their degree program over three years (the load is reduced, i.e. they have fewer courses per year), with the program providing academic support in two mainstream subjects in their first 18 months of study. Extended degree programs in South Africa is an initiative intended to support students from a secondary school system that has not sufficiently prepared them for tertiary education.

Purpose
The main question in this cycle of research was “How do students experience learning events as they transition from 1st to 2nd year in an engineering extended degree program?” The intention of this study was to gain a better understanding student learning and to make recommendations to enhance their learning experience in the extended program. These students are engineering students and as such, their experiences, and the understanding of possible structures that relate to their achievement of success is vital to the engineering education community.
Methodology

Data was collected in two rounds. In the first round, group interviews were conducted with 9 extended degree program students who had just completed a 2nd year mechanical engineering mainstream course. The analysis of this data provided preliminary themes. A second round of data collection using participant observation with 14 students (in the next cohort who were doing the course) was conducted for theoretical saturation. Data was analysed using grounded theory methodology and the variables that emerged were further analysed using Locke’s 6C process (2000).

Findings

The related themes of alienation, agency and learning communities were identified. During the first round of interviews, it was found that the students were not coping in the 2nd year mainstream course, 9 out of the 16 extended degree program students had in fact failed the 2nd year mechanical engineering course.

Alienation

Students felt they had no sense of shared positive experiences and felt alone.

“2nd year, we felt like we were on our own. (The extended programme) makes us alone.” (Student Z1)

“We are all struggling…going to find mainstream students to work with.” (Student M1)

The students felt alienated from the mainstream program and students. In addition, they experienced the system failing them due to the inflexibility of the curriculum and the curriculum requirements to proceed to register the following year. Once a student has failed a course or two, they feel pressurised to register for more courses then they can manage, due to system requirements. “If you have failed some first year courses and had to redo, then some students have a full 2nd load. These students have a full timetable.” (Student TH1).

Heavy load when already not doing well academically leads to poor learning and failing. In order to reduce the load, the 2nd year mechanical engineering course is not in the next semester after physics, the mechanics needed for the course. “physics too long ago.” “wish (the course) was straight after physics.” (Students B1 and TX1, respectively).

Transitioning out of the program’s supportive environment, students also saw changes in teaching; “(The lecturer) doesn’t mark the way (the extended program) marks.” “He gave hints and some spotted and passed.” (Student B1). “Copied tuts since the tuts are too long or we break up and allocate tuts” “we can’t ask questions.” (Student TX1).

Transitioning to learning communities

As a response to feelings of alienation, some students exercise agency and do something to learn for themselves. Often students create their own learning communities to enable knowledge sharing and skills development, including strategy and problem solving. Learning communities were created by an educator or by the students themselves and are self-managed. Once students realise that you can learn from one another in order to succeed, many made the effort to create them. The shared positive experience of learning communities created a sense of belonging and reduced alienation. During second round of data collection and fieldwork, the following comments were made by students that created their own learning community:

“We learn a lot from each other.” (Student M2)

“Others, they work really hard on their own and they don’t pass.” (Student S2)

“Our group is doing really well. We ok.” (Student T2)
“We want to help others but they don’t even come to us.” (Student L2)

Students were observed solving problems together, often speaking in isiXhosa or isiZulu interspersed with English. The students who had formed a learning community, seemed very comfortable in talking to one another, helping each other, laughing. They motivated each other to tackle problem after problem instructed to in the tutorial. They argued about the meaning of a worded problem, but resolved it themselves.

Discussions and conclusions

Since the turn of the century, in-depth studies into student experiences, particularly in extended programs in South African universities, have highlighted feelings of alienation (e.g. Bangeni and Kapp 2007; Luckett, 2012; Case, Smith and Walbeek, 2014). In grappling with the consequences of, and hypothesizing ways in which to address alienation, Davidowitz and Schreiber (2008) and Pym (2013) explored concepts such as learning communities. However, moving from positions of ‘disadvantage’ and negative connotation of inadequateness and the deficit model, Yosso (2005) argues that Critical Race Theory’s community cultural wealth (as opposed to the traditional Bourdieuean cultural capital theory) highlights the alternate capital students have in order to succeed in their educational journeys. Aspirational, linguistic, navigational and social capital, were four out of the six forms of community cultural wealth already in evidence with those students in a learning community. This needs to be explored further in this context.

In the transition from the supportive environment of the first year extended degree into a second year mainstream course, the students experienced feelings of alienation with some showing agentic behaviour by working in communities of learning.

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Appendices

Extended abstract for the workshop: Unpacking the Writing and Publishing Process for Engineering Education Researchers

Lisa Benson, Adam Carberry, Jennifer Case, Kristina Edstrom, Cynthia Finelli, Kate Le Roux, James Swart and Maartje van den Bogaard

Extended abstract for the workshop: Unpacking the Writing and Publishing Process for Engineering Education Researchers

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Context

Academic journals seek to disseminate scholarly research, build expertise, and advance knowledge in their fields. The process of getting an article published in an academic journal is often seen by researchers as a black box, in particular the review processes whereby journal editors come to make evaluations of articles. Authors typically wonder what editors and reviewers seek, how to focus their manuscripts, when and to what degree they can deviate from what a journal typically publishes, and how to interpret each journal’s guidelines for authors.

Many authors of conference papers seek guidance in expanding their work to a level acceptable for journal publication. Some journals provide specific guidelines (e.g., specific percentage of a conference paper that must be extended to be considered for journal publication (Offutt, 2016) or strategies for using feedback on conference papers (Worrall, 2016)), but authors are typically left to interpret vague guidelines about adding original material, background literature, or data analyses.
Approach

The first two-thirds of the workshop will comprise an interactive discussion led by the workshop facilitators to guide participants through the following topics:

- **Key components of a publishable article:**
  - Showing that the study brings forward new insights to the field
  - Situating the study carefully within the relevant literature
  - Explaining how theoretical framework(s) informed the study
  - Explaining the research design choices, including methods
  - Giving a detailed overview of the findings
  - Discussing implications of the study for practice and/or research
  - Demonstrating relevance to the greater field of engineering education

- **Definition of and quality criteria for scholarly research in engineering education, and how quality criteria can be applied in the writing process**

- **Points to consider when submitting a manuscript for publication in a journal, for example:**
  - Alignment between the different parts of a manuscript, logical flow of the argument, and coherence
  - Appropriateness and alignment of the methods for the research question(s) posed; well-justified choices in the research design
  - Well-supported and clearly elaborated findings and claims
  - Clearly articulated findings and conclusions that circle back to the original research question(s) and the broader literature
  - Clearly articulated implications for practice or research in engineering education

- **Purpose and content of a cover letter**

- **Outlining responses to reviewers when submitting a revised manuscript**

For a subset of these components, facilitators will present relevant examples to illustrate the main points. For example, samples of anonymized reviewer feedback will be provided to highlight how reviewers discuss quality aspects of a manuscript or the extent to which authors have articulated the gap in the literature that their study is addressing. Examples of well-crafted cover letters will be provided to demonstrate how editors use the information authors provide in cover letters. Sample formats for crafting responses to reviewers’ comments when submitting a revised manuscript will be provided.

Participants will be encouraged to bring to the workshop a draft of a paper that they plan on publishing in an engineering education research journal. This could be a conference paper from REES that they plan on developing into a journal paper. Participants will individually reflect on what parts of their paper could be strengthened to make it publishable. Small groups will be formed so that facilitators can guide discussions of up to three papers per group. Copies of the Author Guidelines for major engineering education journals (e.g., Journal of Engineering Education and the European Journal of Engineering Education) will be provided to help participants interpret the guidelines relative to the manuscripts.

Each small group will report out on what aspects of their manuscripts they focused on, what aspects of the author guidelines were helpful in strengthening their manuscripts, and identified ways to make the entire process more helpful and transparent.

The final portion of the workshop will comprise an “Ask the Editor” panel discussion about what happens to an article once it is submitted. Participants will be prompted to ask the facilitators questions about the process and facilitators will provide tips on how to make the process as smooth as possible for authors.

Outcomes

Whole and small group discussions will be used to share ideas about the academic publishing process, identify characteristics of scholarly research and publishable
manuscripts, and provide guidance to authors seeking to publish their scholarly work in an engineering education journal. Participants who bring a draft of a paper that they intend to submit for publication will gain insights into how to improve the quality of their work and to implement ideas that will increase the likelihood that their work will be peer reviewed and eventually accepted for publication. Other participants will observe the process of strengthening a draft of a manuscript to make it more likely to be accepted for publication. We will also compile a list of resources, such as foundational work, research methodology references, and review articles, that journals can share with potential authors as they prepare their work for publication in our field. This list will also help build expertise for potential authors beyond those who have attended this workshop. Facilitators will also benefit from these discussions as we identify information currently provided that potential authors find useful in preparing their manuscripts for submission to a journal and information that they wish could be provided. We will make information gathered through this workshop available to all potential authors through our respective journal websites, future workshops, and social media outlets.

References

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BUILDING THE FORESHORE FREEWAYS:
THE POLITICS OF A FREEWAY “ARTEFACT”

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ABSTRACT
During the 1940s and 1950s the engineers and planners of Cape Town were immersed in debates about proposed road infrastructure on Cape Town’s Foreshore. As various alternatives were discussed the tensions between National, Provincial and City government and the Foreshore Board surfaced. This paper highlights one aspect of the story using reports, archived correspondence and minutes of meetings from the time. The paper argues that Foreshore Freeway planning was an inherently political exercise and that Foreshore Freeway infrastructure, in common with other technological artefacts, has politics “embedded” into it.

1 INTRODUCTION
In the centre of Cape Town, overlooking the busiest intersection in the central City, en route to the major Waterfront tourist attraction, and snugly to one side of the International Convention Centre is a freeway, suspended and incomplete. Follow the arc which this road describes and you will see, at the opposite side of the intersection another stub of freeway, also suspended, also incomplete. Elsewhere, more hidden from public scrutiny are four more suspended, incomplete pieces of two lane freeway. These pieces of road form part of the so-called Foreshore Freeway of Cape Town. They are the focus of ridicule, the location for advertising creativity, the source of urban mythology and iconic Cape Town structures. They are also an anachronism of the transport planning process - a process which tends to finish what it starts. How did Cape Town come to have freeway stubs suspended above its centre? What can this “artefact” tell us about road engineering of that time? And what does it mean for us – engineers, planners, South Africans - today?

The story which emerges from these questions is rich and complex, and deeply rooted in Cape Town’s contemporary history. This Foreshore Freeway story touches east into District 6 and north to Government Avenue. It also connects across to the US and to the birth of transport planning in the 1950s, and with the associated development of traffic survey techniques, computers and modelling. The story was influenced by tensions between levels of government, between modes of transport and across professional boundaries and, inevitably, by the South African politics of race. Locating and forming the Foreshore Freeway was, in sum, a complex, protracted set of compromises between multiple actors with many agendas, and is the focus of a piece of research work in progress. This brief paper focuses on one part of that story, on some of the debates which ran from the 1940s to the early 1960s. The focus is particularly on the Eastern Boulevard, the road which runs into central Cape Town from the southern suburbs, and which cuts through the Woodstock/District 6 area.
The following material is drawn from many sources, but largely from the writings of Dr Soloman Morris and government files from the National Archives of Cape Town. Abbreviated referencing is provided, full referencing will be available in the upcoming PhD thesis of the author.

2 THE PRE 1950 FORESHORE DEBATES

The genesis of the Foreshore Freeway scheme can be placed as early as the Paris spring of 1940, when Monsieur Beaudouin (Chief Architect to the Government of France and “first placed town planner in the Grand Prix de Rome”), received a cable from WS Lunn (City Engineer, Cape Town) and JC Collings (Town Planning Branch in City Engineers Dept) requesting his planning advice for how best to use the land being created from the dredging for a new Cape Town harbor (Beaudouin, 1940). Expected to cover 480 acres and situated at the shoreline of Table Bay, between the existing city and the sea, Cape Town’s Council had long recognized the untapped potential of the land but were now in need of some strong planning advice. The Railway Administration, who were co-beneficiaries of the Foreshore land, were unhappy with Council’s plan for the area and had appointed Professor LW Thornton White (“former scholar of the British School in Rome”) and Longstreth Thompson (“town planning consultant of London”) to help them to develop an alternative. The cable to Beaudouin, requesting his input, was the Council’s response to the Railway Administration’s appointment of experts (Cape Town Foreshore Joint Technical Committee (CFJTC) 1948).

As war rumbled in Europe, Beaudouin started his three month sojourn in Cape Town. According to him, there was an easing of tensions between the Cape Town parties as they worked on their separate reports but with “a considerable degree of cross-reference and collaboration”. The resulting plans had a similar approach and “the same essential elements”, which were a largely at-grade Parisian inspired scheme with straight, wide Boulevards stretching to the East and West and a newly developed civic centre. The plan for a Monumental Approach from the harbor and vistas stretching in all directions, ensured that approach to Cape Town by sea (the focus, as this was in a time before commercial aviation) would be most impressive (CFJTC, 1948).

A year later, in March 1941, the City Engineer presented three alternative schemes to Council: the Council’s scheme by Beaudouin of Paris; the Longstreth-Thompson’s scheme produced for the Railway Administration and the original Joint Town planning Scheme created before the various expert advisors joined the process. The tensions were many, but focused on the location of the railway station and the civic centre site. A Committee was set up to broker a compromise plan, but these negotiations broke down, with the City believing that no satisfactory solution could be found while the position of the Railway Administration on the siting of the railway station remained as it was. The Foreshore plan was deadlocked (CFJTC, 1948).

Two and a half years later, in October 1944, local parties lobbied national government to intervene in the stand-off and a Committee was appointed under the chair of Major-General Szlumper. The Foreshore Investigation Committee (Szlumper Committee) sat in February of the following year with the plans developed so far and the Committee made recommendations, mainly relating to the siting of the new railway terminal and following this the Minister of Transport approached the City Council with a suggestion for a new Foreshore Joint Technical Committee (JTC), which was formed and subsequently sat 34 times (CFJTC, 1948).
Monsieur Beaudouin was appointed by the JTC committee and returned to Cape Town in June 1945, where he developed another new plan. After he left, his scheme was handed over to the new Town Planning Office of the City, who developed yet another variant, which was submitted to the Minister for approval. The Minister expressed “keen interest” but wanted to get Beaudouin’s stamp of approval on this revised scheme and also wanted the concerns of the City Engineer who had expressed doubts about the adequacy of the scheme for “motor traffic and parking” to be considered. So, on Beaudouin’s return, the new Town Planning Officer, and Beaudouin developed another plan, which was unanimously accepted by Committee (CFJTC, 1948).

In June 1946, six and a half years after that first cable to Monsieur Beaudouin, and many versions of the plan later, a report, plan, and photos of a model of the proposed Foreshore Scheme were submitted to the Minister of Transport1. It seemed that the scheme would now finally be built. But it was not to be so straightforward.

3 THE 1950’S: “METROPOLIS OF TOMORROW”

In 1949, Solomon Simon Morris became, at the age of 37, the City Engineer of Cape Town, a position which he held until his retirement in 1977. By 1951 “Solly” Morris (as he was affectionately known) and his team had developed somewhat different ideas to those published in the 1947 Plan. Morris argued that the 1947 Plan would require Boulevard gradients in excess of 1 in 10.5 and that there were many reasons to argue that the 1947 plan, so long in the making, was flawed, potentially very expensive and difficult to justify.

He proposed relocating the Eastern and Western Boulevards and adding a Ring Road to the original plan to “allow for circulation”, with “as little disturbance as possible”, and “speedy entrance and exit” for the vehicles travelling (Morris, 1951). By doing this Morris was evoking an emerging post-War view which wedded the fast-moving car with the inevitable, more hopeful, modern future.

In “Metropolis of Tomorrow”, Solly Morris countered the grand boulevards and vistas of the 1940’s scheme with a plan for a modern city. This was a new turn for the planning of the Foreshore. Morris argued for speed, economy and overcoming congestion:

“The importance of efficient traffic circulation in the central city has already been emphasised. The congestion which occurs in the central city to-day is strong testimony of the time-consuming, uneconomical and frustrating complication which ensues from the ineffectual traffic circulation.” (Morris, 1951, p34)

Unfortunately for Morris, through, his arguments for efficiency, commonsense and the objectivity presented in “Metropolis of Tomorrow” were not enough to generate funding and commitment to his plan. His proposals for a Ring Road to pass under the historic and well-loved Government Avenue were controversial and by 1956 another Committee had been formed by Province, with the specific and urgent brief to attend to the location of Boulevard East and its intersection with the Foreshore Schemes. The rest of this paper focuses in on at those particular debates, using records of the meetings held, now stored in the National Archives.

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4 BOULEVARD EAST

4.1 “Certain intersections”

The 1956 Committee, which consisted of representatives from the National, Provincial, City governments; the Railway authorities, the Foreshore Board and the University of Cape Town was briefed to:

“consider various questions relating to the engineering design of Boulevard East, in particular the location of the railway bridge and the traffic carrying capacity of certain intersections”\(^2\).

These “certain intersections” were the central city junctions of the Eastern Boulevard with Oswald Pirow Street, Heerengracht, and Buitengracht.

Hoffman, the National Department of Transport representative, did not think that it would be possible to disperse quickly enough all of the traffic which would enter Cape Town and his concern was that these intersections would restrict the free flow of traffic. Hoffman offered up some calculations to help the discussions using the road capacities of the three approach roads. He proposed a series of flyovers on the Foreshore to give a free flow of traffic. In turn, the City Engineer’s Department did their own traffic analysis, and developed different forecasts. Faced with two conflicting versions of the future, the City and the National Department were at stalemate, and Morris argued “it might well be that the only way to satisfactorily resolve this difference of views would be to await the results of the traffic survey at present being undertaken.”\(^3\)

Another Committee member, meanwhile, Mr Hugo of the Provincial Roads department, appeared to be getting rather frustrated. He argued that if the matter were held over until the traffic survey was completed, it might be found that the properties along the Eastern Boulevard route (frozen in preparation for scheme development) might be “defrozen” and the construction of the Eastern Blvd would become very difficult. He felt that the Committee should continue with their efforts to find a solution and not await the results of the traffic survey.

It is unclear from the correspondence what Hugo’s urgency was, but we do know that the City Engineer before Morris, W.S. Lunn, had already put together a plan for compulsory purchase for the Eastern Boulevard through District 6 in the late 1940’s\(^4\), and that there had been plans for clearing so-called slum properties in District 6 since 1940. In 1953/4 a Master Plan for Housing had been developed, including District 6, and so there was momentum to finalise road plans\(^5\). By March 1956 we have two sets of traffic forecasts (one from Morris and Rudner at the City and one from Hoffman, the National Government representative), and we also have Hugo from Province urging them both along because of frozen properties in District 6.

\(^2\) National Archives Box PAR G14/1 and G14/2, Provincial Administration of the Western Cape of Good Hope file P480 Batch 1.
\(^3\) 19 March 1956 Minutes of Meeting from National Archives box PAR G14/1 and G14/2 027, Provincial Administration of the Cape of Good Hope file.
\(^4\) National Archives box 3/CT 4/1/11/682, file G53/1VOL1.
In some ways this is story of deadlock is very particular to Cape Town, 1956 and yet in other ways this is a timeless story of transport planning: competing tiers of government, personal rivalries, struggles over methods of planning, and agendas or interests masked behind it all but pushing through in various ways.

What was the solution? At the next meeting in May the Provincial representative talked of the attempts made to “cut the gap” between the forecast figures already submitted by the City and National Government, but Mr Hugo argued a third perspective, that the flow along Eastern Boulevard would not be as heavy “as first feared” because of the constrained width of de Waal Drive. It may seem strange in 2011 to hear Mr Hugo voice, in an official document, such a personal opinion, a hunch really, and without the backing of traffic survey but prior to this time much planning of roads was based on estimates of existing flows, judgment and some basic predictions of the future.

4.2 Shopping Diversion

The matter of what to do was unresolved despite the arguments from all sides, but at this meeting these concerns about traffic analyses were superseded by another issue, this time questioning whether the Foreshore Board, who were part owners of the Foreshore land, would want a flyover bridge or a busy road through their planned shopping precinct at the intersection of Hertzog Boulevard and Heerengracht. It was resolved that a report be drawn up for the Board, in order to get their approval and so to be able to address the question of the suggested flyover at the shopping precinct. In conclusion the report of the Committee to the Foreshore Board argued that the 1947 plan was unworkable in its current form and that “desirable though a shopping precinct may be in its present location, from a traffic point of view it can hardly be considered suitable” and that “if ultimate traffic flow is to be efficiently handled some major modification to the 1947 Plan appears inevitable.”

4.3 Back to the Eastern Boulevard

Morris, meanwhile, was not convinced about the necessity for the Eastern Boulevard, and so unsurprisingly the Committee waivered over the wording of the report on it. In a draft which was not sent they said:

“The Committee has not addressed itself – as indeed it was not in a position to – to the question of when or even whether at all in the foreseeable future the Blvd East should actually be built...certain facts have appeared in the course of this conversation which must inevitably give rise to some concern. The present capacity per se of the approach roads appears to be more than adequate for some considerable time; yet the construction of the Blvd East, paradoxically enough, may well give rise to fresh traffic difficulties at its intersections in the Foreshore which are sufficiently serious to necessitate reconsideration of the fundamental concepts of the 1947 Plan”.

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6 Report of the Technical Committee appointed to consider the route, location of bridges and ancillary traffic problems connected with Boulevard East, to be submitted to Provincial secretary. National Archives, Cape Town file PAR/P480 Batch 1.

7 Draft of Report of the Technical Committee appointed to consider the route, location of bridges and ancillary traffic problems connected with Boulevard East, to be submitted to Provincial secretary. Dated 1956 Aug 29. National Archives, Cape Town file PAR/P480 Batch 1.
In the final draft of August 1956 the Committee was more constrained:

“…the Committee wishes to record that it has been expressly given to understand that the Boulevard East Project is to be considered as a fait accompli. For this reason, and bearing in mind that this proposal has been accepted by the authorities concerned, and that development along the route of the Boulevard has been frozen for many years, it desires specifically to refrain from expressing any opinion on the necessity or otherwise of this highway.”8

The response of the Board to this report is not on record, but almost a year later Morris (from the City) and Hugo (from the Province) are still exchanging correspondence about it. In a Confidential memo, Morris remains unconvinced of Boulevard East’s necessity:

“Recent discussions…have made it clear that subsidy for construction of the Boulevard East will not be made available unless certain major design amendments are made…”

“As a consequence two important issues are raised: firstly whether the proposed amendments are justifiable; secondly, in view of all of the difficulties that have arisen in regard to Boulevard East, whether the benefits that would arise from construction of this roadway are, in fact, commensurate with its cost.”

Continuing, Morris argues against the Boulevard East not only from traffic considerations, but also other points of view:

“The route and probably the road itself, was perceived on architectural, or perhaps geometric considerations, rather than those of topography and traffic flow.”

“It is not a true “radial” or “tangent” road. It lies on a route which, from a traffic engineering point of view, appears arbitrary or forced, striking as it does over, and interfering with, three other radials: De Waal Drive, the Main Road and Strand St extension.”

“A truly adequate traffic plan using this [Eastern Boulevard] has not yet been evolved; for example it is hard to see how some form of congestion could be avoided at [four intersections].”

“It therefore seems possible that the principal problem is not the provision of adequate roadway capacity leading into the City; and in any event even if it is, then Boulevard East – bearing in mind its heavy expense – makes a relatively ineffective contribution to its solution.”9

Morris opposes the construction of Boulevard through District 6 for many explicit reasons and perhaps also for reasons we are not party to. A terse and dramatic response comes from Hugo in return, in July 1957. There is talk about a new Committee, but Hugo is threatening to remove himself from any Committee which does not agree to Boulevard East. A new “Western Exit Technical Committee” is set up, with the terms of reference that make it clear: Boulevard East is a “fait accompli”. Once again it looks like the debate is closed and a new Foreshore Plan can finally be put in place. Or can it?

4.4 Shopping revisited

Early in 1958 an alternative for Shopping Precinct problem is proposed, a deviation of the Eastern and Western Boulevards which would bypass the proposed Shopping Precinct completely but the National Department of Transport are not convinced and argue that

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8 Report of the Technical Committee appointed to consider the route, location of bridges and ancillary traffic problems connected with Boulevard East, to be submitted to Provincial secretary. National Archives, Cape Town file PAR/P480 Batch 1.

9 Memo June 27, 1957, National Archives file PAR/P480 Batch 1.
long term plans must include linking Boulevard East and West. There is a breakdown in communication. The City are prioritising a Ring Road; for the Railway and Habour’s Board the Shopping Precinct (presumably important for revenue raising) is key; the Province are anxious to get the Eastern Boulevard built while the National Department of Transport are prioritising efficient flow of long-distance through traffic. Morris, meanwhile, is hopeful that the results of the traffic survey can resolve the many tensions.

4.5 Traffic survey

By February 1958 the traffic survey had been completed and the analysis work done. The traffic analysis report confirmed what many had argued, that there would indeed be congestion at the Shopping Precinct/ Close intersection, but Mr De Bruyn, the representative from the Foreshore Board was cynical, arguing that traffic congestion would occur “not only on the Hertzog Boulevard/ Heerengracht intersection which had been specifically singled out, but also at every intersection in the City.”

Although the traffic analysis had given information, it had not resolved the Committee debates. Not surprisingly, the Board were unimpressed. In June 1958 the Board Chair noted that although this Committee had been in existence since August 1957, no progress on their brief - the actual planning of the Western Exit of the Eastern Boulevard - had yet been made. The Board insisted that the Shopping Close must stay and in reply the National Government threatened to withdraw funding explaining that “National Road Funds had perforce to be spent on the best schemes only, and if the scheme was not a workmanlike one from the engineering point of view, there would be no alternative but to withdraw from the scheme.”

In retrospect this position of the National Government sounds like brinkmanship masquerading as professionalism. Who was to judge the “best” and most “workmanlike” scheme? Clearly there were several contested and competing views between layers of government about what “best” for the Foreshore actually was.

5 THE “RESOLUTION”

As we know, the eventual scheme built on the Foreshore was dramatically different from the one debated here, and the idea of bypassing the Shopping Precinct intersection completely was the one which did ultimately win through, as the whole Foreshore development was bypassed by the Foreshore Freeway in a plan developed in the early 1960s using a new generation of overseas experts. Ironically the shopping precinct so beloved of the Foreshore Board (now called Piers Place) did not develop in any significant way, perhaps bypassed itself by suburban developments elsewhere. The eventual Foreshore Freeway scheme adopted in the early 1960s was far more substantial than anything discussed in the late 1950s.

In 1959 the Chair of the Foreshore Board told the press that it was “too late” to review the plan for the Eastern Boulevard and the Eastern Boulevard, which had been part of a provisional town planning scheme for the redevelopment of the District 6 “slum” area since 1940, was one of the few sections of Solly Morris’s promised “Metropolis of Tomorrow” built (Barnett, 1994; p178). The Eastern Boulevard, which the City argued against but which the National and Provincial governments eventually insisted upon has the dubious

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10 Minutes of Meeting 3, 26 February 1958, National Archives box TRE/7/6/D Vol 1.
11 Minutes of meeting 18 June 1958, National Archives box TRE/7/6/D Vol 1.
12 Cape Times 3 September 1959.
distinction of being the cause of the first large scale demolitions in District 6, starting in 1960.

6 CONCLUDING REMARKS

Given South Africa’s history of Apartheid planning it is easy to draw conclusions about the politicised nature of South African urban planning and housing. Whether transport planning is as politicized is more debatable – with some still advocating, as Solly Morris did in the 1950s, that transport planning is a more objective process, based on scientific data collection and modeling. After researching the detail of road planning practices, however, the conclusion must surely be reached that road planning is as politicized as urban planning. Struggles for power between levels of government, and between individuals and institutions, permeated the engineering meetings of the 1940s and 1950s as surely as they permeated the urban planning of the day. We can conclude then, that road planning, is political, but what does saying that mean for the Foreshore Freeways, and for transport planning practice today?

Studies of technology from elsewhere offer some pointers. Langdon Winner asked “do artefacts have politics?” and describes the case of Long Island’s parkways, which were built as access routes from New York City to the beaches of Long Island from the 1920s (Winner, 1986). They were important as they provided one of the few means for New Yorkers to leave the crowded city and experience leisure in the open. The bridges over the parkways have achieved some notoriety for their embedded racism, as they were low enough to stop buses (mainly used by poorer African-Americans) to use, but suitable for rich car owners to pass under. Hence the bridges embedded politics of race which permeated the use of the road long after those who were involved in their planning and construction had gone.

Given that the debates about the form and location of Cape Town’s freeways were clearly politicised exercises, what can we say about the artefacts of those debates, the constructed (and incomplete) freeways which remain? The general argument made here, and repeated through many other case studies of technical artefacts and systems, is that the seemingly neutral urban road infrastructure we now live with have embedded in them their social and political histories (Hughes, 1983; Bijker et al, 1987; Bijker and Law, 1992; Garb, 2004). As we have seen above, these histories are not neutral, and they are not simple. In the case of the Foreshore Freeways they reflect the power politics of decades of negotiations, and so the conclusion is: the Foreshore Freeways have politics. The politics of the Foreshore Freeways may not be as simple as the politics of the Long Island Parkways but they, too privilege some actors and interest groups over others as they continue to describe the transport infrastructure, and city, which was seen as “best” by the engineering and planning of the 1940s to 1950s.

When considering what to do with these political artefacts from the past we would do well to reflect on their histories, and on what politics are embedded in them.
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