Proceedings of the First Biennial Conference of the South African Society for Engineering Education

10 – 12 August 2011

Stellenbosch, South Africa

Edited by Brandon Collier-Reed
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Message from the President of SASEE

I am delighted to be welcoming you to the very first biennial conference of the South African Society for Engineering Education (SASEE). Starting in 1997 there have been four national conferences on engineering education: in 1997 in Cape Town, in 2000 in Vanderbijlpark, in 2002 in Durban and in Pretoria in 2006. SASEE intends to build on this rich tradition and provide the formal structure to ensure that we hold a regular biennial conference drawing wide participation from all engineering education institutions in the country.

We were overwhelmed by the enthusiastic response to our call for papers and this has resulted in a rich and varied programme for the three days of the conference. There is no doubt that this will set the scene for engaged discussions around the challenges and opportunities that we as academics in the field of engineering education currently face.

These proceedings are a full record of the academic contribution of the event and provide a good reflection of the quality of our scholarship in engineering education. A rigorous peer review process has set a high bar for what it takes to present at this event.

I am enormously grateful to my energetic and wise Board who have steered SASEE towards our launch event, and in particular to the Conference Organising Committee who have worked night and day to bring this all together.

I hope that you, the delegate, have obtained new insights and energy for your work both in attending this event and consulting the proceedings. We look forward to your continued involvement in the SASEE community.

Jenni Case
SASEE President
Conference Review Procedure

These proceedings are a published record of the First Biennial Conference of the South African Society for Engineering (SASEE). The purpose of these proceedings is to disseminate original research and new developments within the discipline of Engineering Education.

All papers and extended abstracts accepted for this conference went through a multiple-review process prior to publication. Authors initially submitted extended abstracts which were double-blind reviewed by at least one member of the SASEE or Centre for Research in Engineering Education Executive. Based on the outcome of this review, authors were invited to either develop this extended abstract into a full paper, or were invited to revise their extended abstracts based on the reviewers comments for resubmission. The resultant papers and extended abstracts were then further reviewed by at least two reviewers using a double-blind peer review process. Authors were required to consider and implement the suggested changes where required.

The reviewers for the papers and extended abstracts were drawn from the SASEE Executive, SASEE membership, and the Centre for Research in Engineering Education (CREE) as appropriate. The organising committee did not participate in the review other than to consider reviewer comments and give feedback to the authors in the traditional way.

The rejection rate for full papers was 13% and for extended abstracts was 33%.

SASEE Biennial Conference Organising Committee, 2011
A/Prof Jenni Case (UCT)
Dr Debby Blaine (US)
Mr Keith Jacobs (CPUT)
A/Prof Brandon Collier-Reed (UCT)
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Student Identity and the Need to Make Classroom Mathematics Relevant to Engineering Practice

Tracy Craig

Academic Support Programme for Engineering in Cape Town (ASPECT) & Centre for Research in Engineering Education (CREE), University of Cape Town, South Africa

Tracy.Craig@uct.ac.za

Abstract

Cobb and Hodge’s (2005) identity theoretical framework suggests that learning is facilitated if normative identity (realised and co-constructed in the classroom by lecturer and student) is reconciled with core identity (the trajectory of who the student is and where he feels he is going). The cohort of students involved in the study discussed in this article largely embodies trajectories of social mobility, with a great willingness to study engineering for its role in providing a way out of poverty rather than for the sake of the discipline itself. The pedagogic implication is that teaching must proceed sensitive to the reality of the students which is that they potentially have little idea what engineering entails other than a route out of a disadvantaged background.

Introduction

The mathematics instruction for students enrolled for engineering studies at university needs to be relevant to engineering practice and correctly calibrated and scaffolded for the students’ levels of mathematical competence in order for the desired learning to occur (Porter and Fuller, 1998). First-year mathematics courses are often in danger of being taught at too abstract a level and not maintaining a connection of relevance with engineering practice and more advanced engineering studies (Craig, 2010; Holmes and Spilker, 2007). Students enrolling for a university degree in engineering do not necessarily begin their studies with an existing idea of what engineering is, other than a professional degree with good employment prospects. This disconnect has implications for classroom activities designed to make connections between classroom mathematics and post-graduation practice as well as the use of mathematics in their engineering courses.

The Academic Development Group at the University of Cape Town has undertaken a longitudinal, cross-faculty investigation into the experiences of a cohort of students who registered at UCT in 2009. I am the representative, on the project team, of ASPECT, the academic support programme in the Faculty of Engineering and the Built Environment (EBE). The project has produced a large quantity of data in the form of questionnaires and interviews. For the purposes of the investigation discussed in this article, the data were interrogated for student expressions of “trajectory”. Analysis of the data uncovers a recurring theme of the students expressing their sense of who they were in secondary school and where they hope to go, who they hope to become, through the attainment of an engineering degree. The theoretical identity framework designed by Cobb & Hodge (2005) and Cobb, Gresalfi and Hodge (2009a, 2009b) was found to be useful, both for framing what emerges from the data and for the inevitable implications for classroom instruction.

We ask the question “What core identities (the trajectory of who the student is and where he feels he is going) are revealed by the students (this cohort, on this data set) in the context of their enrolment for engineering studies, and what are the pedagogic implications?”
Theoretical framework

Cobb & Hodge (2005) define three key constructs of identity from a situated perspective, namely normative identity, personal identity and core identity. These constructs are informed by prior theoretical perspectives on identity development, in particular Boaler & Greeno (2000) and Gee (2001, 2003) and developed through empirical data analysis of a classroom design experiment by Cobb and Hodge. **Normative identity** is defined as the obligations the student understands she needs to fulfil, in the form of social norms and mathematical norms, in order to become a mathematical person. **Personal identity** is involved with who a student actually becomes in the mathematics classroom, her affiliations or alienation with classroom activities (Cobb, Gresalfi and Hodge, 2009a) and her assessment and valuation of her own and other students’ mathematical competence. **Core identity**, the construct which is of primary interest in this article, refers to a student’s envisioned trajectory, who they see themselves to be and who they want to become. A student’s core identity can also be associated with their “life story” which resonates (Cobb, Gresalfi & Hodge, 2009b) with the identity theoretical perspective of Sfard & Prusak (2005).

Cobb & Hodge (2005) argue that their (empirically grounded) identity constructs allow us to account for “students’ persistence, interest in, and motivation to engage in mathematical activity as it is constituted in that classroom” (p. 31). Normative identity is co-constructed by teacher and students; the reconciliation of aspects of core identity with the classroom normative identity is correlated with affiliation with mathematical activities.

… building on Boaler and Greeno’s work, normative identity as we define it comprises both the general and the specifically mathematical obligations that delineate the role of an effective student in a particular classroom. A student would have to identify with these obligations in order to develop an affiliation with classroom mathematical activity and thus with the role of an effective doer of mathematics, as they are constituted in the classroom. Normative identity is a collective or communal notion rather than an individualistic notion.

(Cobb, Gresalfi and Hodges, 2009a, p. 43)

The constructs of Cobb & Hodge (2005) have been found useful in this article for providing us with a vocabulary for addressing issues related to identity, alienation and classroom community. The construct of core identity in particular was found to be evoked by the student interviews and other data collected for this analysis. Students enter engineering studies with an existing envisioned trajectory related to their intended degree. The reconciliation (or lack of reconciliation) between core identity and classroom normative identity impacts directly on the student learning experience. An understanding of the students’ envisioned engineering and mathematical identities can help the teacher design classroom activities to support learning.

Research Methodology

The analysis discussed in this article forms a part of a larger, cross-faculty, multidisciplinary, longitudinal project located within the Academic Development Programme at the University of Cape Town. The project was initiated in 2009 to investigate the experiences of the first cohort of university students who had completed the New Senior Certificate examinations at school and is focused on access and throughput of students from disadvantaged educational backgrounds. Data collection took the form of a questionnaire, two interviews (2009 and 2010), a mathematics and language history, and a technology questionnaire. Data collection is ongoing in the form of interviews. The data for the analysis discussed in this paper is taken from the 2009 interviews and the mathematics and language histories, specifically from the
students registered for a degree in the Faculty of Engineering and the Built Environment (EBE).

The students enrolled in the study, across all faculties, largely come from disadvantaged educational backgrounds. Prevalent among their backgrounds are broken homes, poorly educated parents, inadequate housing, communities rife with drug use and violence, classrooms without teachers or sufficient books, and lack of educational support from teachers and peers. The EBE students were all enrolled in the Academic Support Programme for Engineers in Cape Town (ASPECT) in 2009; I was their mathematics lecturer. ASPECT is a first-year programme and the students join the mainstream cohort from second-year onwards. Fifteen ASPECT students, seven women and eight men, took part in the project and continue to take part in the interview schedule (at time of writing, these students are in their third year at university). The students represented four engineering departments: mechanical, electrical, chemical and civil engineering.

**Results**

Directing the question “Where do these students want to go; who do they want to become?” at the data, certain answers emerge. The most prevalent answer is that the students want a degree from a university with an excellent academic reputation, a degree which can reliably be expected to get them a good job. The reason why these students have chosen engineering is not particularly for the discipline itself, but because they recognize in themselves, or had that recognition imposed upon them by a bursar, the skills necessary for success at engineering (such as proficiency at mathematics and physics). For instance, Nwabisa wants an engineering degree because “it counts” and has chosen UCT as “the best university in Africa”.

Tsego sees herself as having a career involving chemistry (either medicine or chemical engineering) – working in a lab in a white coat. She imagines herself earning, having worked hard for a good and “meaningful” degree at a respected university: “UCT is the best, wherever you go, we used to go to Career Exhibitions and they would tell us, ‘If you aren’t at the University of Cape Town, you should be at the University of Witwatersrand or UP’, so UCT was the best and I, because I was the best I decided to choose the best, so I am here.”

Senzo actually chose accounting as his first choice on his application form and engineering as his second. Now, finding himself in electrical engineering, he admits to being puzzled at the relevance of what he is studying in physics, but that does not matter. He is passing and is slowly but steadily approaching graduating with a degree with which he can get a good job and that is all that apparently matters to him.

Siphilisiwe considers that UCT is “the best university, you know, in my opinion, you know I thought I wasn’t going to go to any university but UCT”.

John discusses quite passionately how Engineering is the only subject of tertiary study known in his community – if you study at university, what you study is Engineering. Almost coincidentally, he is happy in his chosen field, but he speaks about how he wants to alert his community to the wider options available. [Concern about students’ ignorance of wider options and determination to choose a professional degree programme straight out of secondary school was publicly expressed recently (2011) by Dr Max Price, Vice Chancellor of UCT.]
Philile refers to his “future look[ing] good” because of his choice of study, which he went into on advice from others who suggested Engineering studies because of his skill at mathematics.

Escape or upliftment from poverty and disadvantaged circumstances was the next most prominent theme in the data, inevitably tightly entwined with the theme discussed above, that of the buying power of a degree. Asked to talk about herself, almost the first thing Nwabisa says is “I come from a disadvantaged family, my mom was not working, my dad was the only one working but I think at Grade 10 he left and he decided OK, and then he left and then ja, so we were kind of struggling financial.” (interview). John says “I began to see the future especially when I was doing grade 12 I saw how are the living conditions at home then I asked myself how can I change them then there was only one answer for that question education and no one can take it away from me but I can use it to get a better life for me and my family and also do something to help in the community” (mathematics and language history).

In the pool of 15 students taking part in this study, only two are studying engineering for the sake of the discipline itself. One of the students had a friend whose father was a civil engineer and her observations of his work had inspired her to follow a career as a civil engineer. Another student had seen programmes on television associated with engineering and had been similarly inspired to study mechanical engineering. Other than these two examples, none of the students gave any evidence that their chosen field of study was for the sake of the discipline rather than social mobility.

The theme of skill at mathematics is strongly present in the data. Naïve interpretation of the data might conclude that the students are studying engineering for the sake of the mathematical content of the subject. Such an interpretation would be insufficiently nuanced for two reasons. First, the interviews and mathematics and language histories explicitly address questions related to mathematics to the students; it is inevitable that there would be much discussion of mathematics in the data. Secondly, the student narratives suggest that the path of reasoning was “I am good at mathematics. Taking advantage of that skill, what degree can I get at university which will lift me and my family out of poverty?” It is inevitable that discussion of why they chose to study engineering would result in talking about their skill at mathematics.

**Trajectory of one student: Senzo**

Each interview lasted approximately an hour. As such, there is a great deal of text in the interview transcriptions from which excerpts can be drawn to develop an idea of a student’s envisioned trajectory. To illustrate one student’s situation, passages have been shown below from Senzo’s interview. The evidence is necessarily only a portion of that available in the full interview transcript. Notably absent from the selections below are many more references, present in the interview, to how hard this student works, how dedicated he was to study of both mathematics and physics in high school and how focused he is on passing.

Interviewer: OK, so do you think you were a successful student?
Senzo: At my school? ... I think.
...
Interviewer: So what made you a successful student?
Senzo: To study hard.
Interviewer: Ok
Senzo: It’s like when I was, because in Grade 10 we didn’t have a Maths teacher,
right ne, so in Grade 11 our Maths teacher have to start us from scratch, so
he didn’t complete the Grade 11 work, same applies in Grade 12. When I
saw that in June exam in Grade 12, I got 40% and I was like ‘Eish’, then I
started thinking, ‘no I am not going to do this again’, then I try hard, like I
was like Grade 12, then at 5 o’clock I wake up and go to study every day
after the June examination, we continued doing that and then in trial I got
around 69% in Maths, then continued waking at 4, then in the final I get
83%.

Interviewer: OK, so besides the studying how important was your self image at school
in your final year?

Senzo: Like I can say I learnt, I didn’t mind whatever people were saying about
me as long as I know who I am ... I just forget everything they are saying
and focus on my life..

Interviewer: Why did you come to UCT?

Senzo: [My teacher] told me it’s the best school in South Africa ... So I chose it
because I want to be in the best school, ja

Senzo: Like here my first choice was B.Com Accounting ne, but they reject me,
then they wait to put me in Electrical Engineering.

Interviewer: So now you are doing, what are you doing?

Senzo: Electrical.....

Interviewer: So you were admitted into Electrical even it wasn’t your first choice?

Senzo: It was actually my second choice

Interviewer: But are you still happy doing that?

Senzo: Ja, I’m still happy.

Interviewer: Or you still want to do your Accounting?

Senzo: No, I don’t want to change now.

Interviewer: What do you do when you [and your friend] are together besides
studying?

Senzo: Besides studying, chilling.

Interviewer: Chilling?

Senzo: But I just chilling for a few minutes because most of the time I am
studying ... Ja, just chilling like for watching TV, 30 minutes just to
relieve the mind, then after 30 minutes for back to the book.

Interviewer: So have you found a girlfriend yet?

Senzo: No ... I don’t want because it’s like she is going to disturb me in my
books. I don’t want anything to disturb me.

Interviewer: OK, so you want to stay focussed.

Senzo: Ja, stay focussed.

Interviewer: What role do you think Maths is going to play in your programme?

Senzo: Ja, I don’t know yet, because like in Physics I thought I am going to do
like the part, the Electrical part, but I’m doing Projectile everything, I’m
still researching exactly why I am doing Physics and Maths in Electrical
Engineering, ja.
Senzo is at UCT because it is the “best school in Africa”. He chose two academic departments (Accounting and Electrical Engineering) both among those programs of study typically suggested to people who excel in mathematics. Although Electrical Engineering was his second choice of study and despite the fact that he does not understand why his current topics of study (such as projectile motion) are included in the degree, he is happy with where he is because he is passing. Each student completed a background questionnaire, from which data it can be seen that Senzo was brought up by elderly grandparents in the rural Eastern Cape, went to schools with insufficient and poorly prepared teachers, insufficient textbooks, exposure to violence, and lived in a community where drug use and violence were rife. An engineering degree (or one in accounting) would provide potential for economic and social upliftment for him and for his family.

Discussion

The students taking part in this study are hard working students who were successful at school, winning academic (and other) prizes. They continue to be hard working at university, tightly focused on passing and achieving academic success, often to complete exclusion of a social life. A repeated motif in the student interviews and in the mathematics and language histories is the information that the students made a decision in secondary school, or in some cases as early as primary school, to study engineering, either as a discipline for its own sake or, far more prevalent, for its promise of a better future for themselves and their families. This study suggests that, in a majority of cases, the fact that we are teaching them engineering is irrelevant. We could be teaching them aardvark farming and, as long as UCT aardvark farming degrees are respected and internationally recognized and jobs in aardvark farming are thick on the ground, the students would be thrilled.

I have discussed elsewhere (Craig, 2010), as have others (Porter and Fuller, 1998; Stevens et al, 2008), that drawing explicit links between classroom activities and real-world engineering is necessary for development of engineering identity, and that such identity is advantageous for engagement with studies and ultimately graduation. Employing the language of Cobb and Hodge’s key identity constructs, such an approach attempts to reconcile the co-constructed normative identity developed in the classroom with a core identity associated with an envisioned trajectory towards becoming an engineer. The findings of the study discussed in this paper have continued the argument and increased the necessity that connections need to be made between the classroom and real world practice. The students all necessarily have a core identity in some way connected to studying engineering, yet their envisioned futures are not so much as practising engineers but as people who have escaped poverty by acquiring through hard work a degree with strong potential for getting them a good job. The data available to me in this research project is almost entirely confined to students in the academic support programme. Students enrolled for mainstream studies might have a similar view of engineering to the students discussed above, or it might be the case that the more affluent students enrolled for mainstream studies exhibit a core identity more in line with an “engineering identity”.

I tend to think of my students as having some sense of identity similar to “I am a novice engineer” and I consider it my responsibility to nurture that sense and develop it by showing how the mathematics we encounter in the classroom can be used in more advanced engineering studies or in real-world engineering. Within this context I have designed classroom activities based on real world engineering examples and projects aimed at allowing students to personally discover classroom mathematics in real world engineering (Craig, 2010). These activities have assumed a degree of interest in engineering mathematics, with
me seeing my role as providing links between their understanding of mathematics in engineering and real world practice. With the insight gained from the study discussed in this article I recognise that the students might have far less of an understanding, however partial or flawed, of the role of mathematics in engineering studies and practice. While the activities and projects I already have in place can still be seen to have value, I recognise that a more fundamental level of alerting the students to the role of mathematics in engineering is required. With a class of students who have a good idea of what engineering entails and with some interest in the real-world activities of an engineer, there is some (but not much) excuse for a mathematics educator to take for granted that the students can see the potential use of first-year mathematics in engineering. With a class of students who have little to no idea of what being an engineer means or what the work of an engineer might entail (despite some of the interviews in this project taking place in the second semester after exposure to their Introduction to Engineering courses), the educator needs to be constantly making clear what role classroom mathematics is playing in the overall degree structure.

If my aim is to teach the students engineering mathematics in such a way that they recognise its relevance, enjoy it and can continue to 2nd-year mathematics with a minimum of trouble then I want the normative identity which I co-construct with the students to reconcile with their existing core identities. Their envisioned trajectories, central to their core identities, are towards being an engineer. However, a key point worth noting is that, although they are determined to become engineers, it is not for the sake of the discipline itself, nor with much or any understanding of what real-world engineering entails, but rather because they understand engineering to be a career with good employment prospects and the potential to lift them out of poverty.

I consider enrolling for engineering studies for purposes of social mobility and economic upliftment as good a reason as any. Our role as engineering educators, under these circumstances, is to develop an understanding of what engineering is and how the specific subjects we are teaching fit into the structure of the degree programme. In the current educational climate in South Africa, we are fortunate to have the opportunity to contribute to the socio-economic ambitions of some of the top students in the country.

References


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A Helicopter View of Engineering May Assist First-Year Students in Performing Better with the End Goal in Sight

Hannes (JH) du Toit

Faculty of Engineering, Potchefstroom Campus, North-West University, South Africa.

hannes.dutoit@nwu.ac.za

Abstract

Engineering students at North-west University start their training programme with a helicopter view approach of engineering practice. Professional Practice I (PP1) was developed to expose the students to realistic engineering practice parallel to the training in theoretical modules. This 24-credit module affords the students the opportunity to practise the engineering process, already in their first year of study, with a real project developed for a real client with real needs.

This module of training is based on Project-Based Learning (PBL), implemented by several universities around the world as an active learning style of teaching. There are different approaches to PBL globally, and we tried to implement a PBL style to best suit our needs in South African context. Since we only implemented the training programme in its current form in 2010, there is no scientific proof yet what the impact will be on the quality of training in the engineering program, but we hope to equip students to ‘take greater responsibility for their own learning, with the benefit that they develop a wider range of transferable skills such as communication skills, teamwork and problem-solving’ and to ‘develop better reasoning ability and have consistently higher levels of satisfaction (Savin-Baden & Wilkie 2004) (p11).

With this new style of teaching at NWU, we also try to have real projects from industry and the community to find useful applications for the funds and energy spent on the projects. It seems that ECSA also realized the value of this programme, and referred to this new training style as follows: “The faculty has embraced project-based-learning, and implemented it in a number of places. In particular the first-year course Professional Practice I (FIAP172) and second-year course Professional Practice II (FIAP271) apply the concept in a way previously not thought possible at first-year level.” (ECSA visit Leaders Report, May 2011.)

With no exam or tests for PP1, assessment is focussed on progress of the projects in small groups, supervised by tutors, with the application of the engineering process. This ensures that the groups are not assessed on the difficulty of the project, but on the method they followed to solve the problem.

A lot was learnt from international visits, literature and personal experience before this module was designed and implemented in its current form. It is only a starting point for research and change for the future; therefore this paper is only a descriptive approach to initiate debate on this topic. The module is still far from perfect but at least it is the first step to assist students used to surface learning ‘to engage in the sort of learning deep learners do spontaneously’ (Biggs and Tang 2007)(p13).
Why this new approach

In our own exposure to active learning we decided to start small, but to have first-hand international experience. After a very small fun project on the North-West University (NWU) campus, we decided to take the winning team to the Netherlands to experience active learning styles at the Technical Universities of Eindhoven (TU/e) and Twente (UT). With collaboration between the NWU, TU/e and UT we draw from the experience from our colleagues in Europe. The following quotation inspired me to design and implement the South African version of PBL as described in this presentation:

> "In our experience young engineering students fresh from school are curious to solve real problems. The engineering student wants to learn to think like a professional engineer and behave like an Engineer. Project-Led engineering education brings in an element of realism from the beginning...even on the first day of the engineering degree programme." (Powel & Weenk, 2003)

Other advantages to convert to PBL in certain modules of the programme are the different dimensions of learning as described by Kolmos et al (2008):

- **Cognitive learning** – learning is organized around problems and will be carried out in projects (problem solving strategies)
- **Contents learning** – interdisciplinary learning across traditional subject-related boundaries and methods. Analytical approach as theory is used in the analysis of real life problems.
- **Collaborative learning** – where learning takes place through dialogue and communication. Students are not only learning from each other, but they also learn to share knowledge and organize the process

From many publications on PBL it was clear that the advantages claimed are worth trying out with the new generation. The new generation are equipped with different skills compared so students from the past and if their energy could be directed towards self-directed learning skills, they may surprise the educators.

The Professional Practice 1 module, in its current form, was implemented in 2010. A combination of literature reviews, international exposure and teaching experience of more than a decade led to the design of this programme. It was accepted by ECSA at their accreditation visit earlier this year with great enthusiasm.

> Some innovative approaches in developing relevant competencies and skills by the introduction of the Professional Practice Modules by the Faculty have had a positive impact on the students. (ECSA Team Leader – Dr Raymond Els)

Some other comments from the report also indicated that this teaching programme is on the right track.

The team was impressed with the very positive feedback from students, particularly relating to Professional Practice I and II. The format of these courses appears to stimulate enthusiasm for engineering work and inter-active project management.

The Faculty is to be congratulated on the success of the Professional Practice modules (FIAP172 and FIAP271). The teams are multidisciplinary, but their training has not been specialised at this stage of their training. Progress in the assignments is assessed by a combination of reports and interviews.

**Structure of Professional Practice 1**

Professional Practice 1 (PP1) is the first real engineering contents module for students. They are used to school style teaching and to start the module with an active learning approach will be too much for them to digest.
The module is divided into three study units, each with a very clear teaching goal:

- **Study Unit 1** meets the learners where they were left by the South African school system. The unit starts with an almost school style teaching method. They start with lectures on the basics of the engineering process and with individual class activities, and class tests. Then they progress towards group activities in class and towards practising the basic skills needed for the rest of the module.

- With **Study Unit 2**, groups develop in teams, and with a real community project with a real client they continue with the assistance of tutors, whilst applying what they had learnt in Study Unit 1. The role of the lecturer has changed from teaching to facilitation, and no more formal lectures are presented. With communication on eFundi and regular feedback on “Forums” the learners are informed about their progress, and an environmental friendly, paperless assignment and assessment system opens the opportunity to run this Study Unit with distant learning clusters.

- With a detail design in hand, **Study Unit 3** has changed to intergroup communication and the practical implementation of the design. Three teams have merged to form an engineering company with Marketing, Configuration control, Manufacturing and Assemble and Test departments. This “company” will independently manage the company towards a final product. The lecturer and tutors continuously observe the progress, assess it and give feedback on it.

**Selecting groups and Group dynamics**

The students need to experience group dynamics with diversity. With a dominant Afrikaans-speaking student population, it was decided to do a MBTI on them and to compile groups as diverse as possible from the results. To prevent majority domination in the groups, the English students were put in groups in such a way, that they have a 40% presence in their groups. A limited number of groups had non-Afrikaans presence but all the groups have to do all their documentation in English. Field of study plays no role in the selecting process for setting up the groups. The groups are exposed to group diversity and the challenge is to convert the group to act as a team with common goals.
Documentation and Communication

As prescribed in all PBL training programmes, official meetings take place with an Agenda, Minutes and Action List. Each student gets the opportunity to act as Chairperson, Secretary and Board Writer. These procedures are practised in class first before they start their own meetings under supervision of a tutor. The tutor’s role is to ensure that every meeting is held in a specific manner to embed professional meeting procedures. All meetings are scheduled on GroupWise and the facilitator is also invited.

The facilitator does not have to be at all the meetings, because of the tutor’s presence. The tutors report any difficulties with the group and the facilitator can visit unannounced to observe the quality, or to address problem areas.

Adding to the scheduling are reminders and the Agenda for the next meeting to ensure that the Agenda is available to all who could be present. Agenda, Minutes and Action Lists are also published on e-Fundi to have all progress available on one electronic platform.

![Figure 2. Regular small group meetings](image)

Meeting the client

Visits to the client help the student to have a better understanding of the problem. Most students have not had any exposure to a technical environment before. The trip to the client’s world gives them that real-life experience they need to focus on the problem. Three teams work in parallel on the same topic before merging to form a business unit to solve the problem.

![Figure 3. Determine the client’s needs](image)

After the visit to the client, each individual prepares a concept design and does a PowerPoint presentation to the rest of the team. The team ranks the individual ideas and with a brainstorm session from there develops a team concept design. A follow-up meeting with the client, together with the other two teams working on the same topic, sets a single possible
solution to the problem. The merging of the teams and their ideas ends in a Requirement Specification and all parties – the team, client and facilitator – agree on the end product and the budget available to the business unit.

Operating as a business unit

Once the merged team has decided on a business structure to fit the specific project, they appoint a CEO and HOD’s for all departments. The business unit has the freedom to set its own work schedule, meeting frequency, and deadlines (as agreed with the client and facilitator). They have to do a Work Breakdown Structure and set a Gantt chart to guide them through the project. All meetings have Agendas, Minutes, Action Lists and individual Journals as a documented trace of their progress. All these documents are published on an electronic platform (e-Fundi) and are visible to the tutors and facilitators. Regular peer group assessments reflect individual participation.

The business unit has to do the detail design and the development of a prototype as stated in the Requirement Specification. They have to manage the workload and ensure that each team member is doing his/her part, guided by the Action List. They manage the project as prescribed with a Gantt Chart and official progress meetings. Funds for the project were transferred to the student’s personal bank account that was selected by the group as head of finance. They do their own procurement and organize the manufacturing activities.

Figure 4. Manufacturing and assembling of projects

Parallel to the manufacturing, configuration control ensures that the latest version of design is used for manufacturing and updates the data pack if any changes in the design occur. The Marketing department starts with a marketing campaign for the exhibition day to invite the public to the event. Radio interviews, magazine and newspaper reports, websites and FaceBook sites ensure that visitors know what to expect on this day.

The advantage of having different projects is that students can learn from each other. They also make use of the exhibition to visit the other projects to find out what they did and how they solved their problems. On this day they are also exposed to different technical fields to add to their field of experience needed for the modules to come in their senior years.

Assessment

There are no assessments in the form of traditional exams or tests for this module. We start Study Unit 1 with individual exercises in class immediately after a lecture/DVD/guest speaker from industry to apply what was learnt. This process develops towards group activities; first in class and later in group meetings after class. Group activities are supervised by the lecturer in class, and meetings after class are supervised by undergraduate tutors. In
the group meetings the students are afforded the opportunity of becoming familiar with meeting procedures and documentation. Peer Group Assessments are also practised during this study unit.

**Figure 5.** Project evaluation and exhibition day

From the second study unit a double track of assessments are implemented. The first track is called the GAMA-PGA system, where the qualities of the meetings are assessed as well as the quality of the individual inputs to the team’s goals. The G represents the Gantt Chart to be used weekly to clarify the strategic goals of the team. The first A represents the Agenda to be prepared for each meeting and the M reminds them of the Minutes of the previous meeting to be available and approved. The Action List spells out in detail what was expected from each team member for this meeting. A Peer Group Assessment confirms the quality of work done by each individual comparing the results with the assignment on the Action List. These results are updated weekly on eFundi and the students can track their results, by comparing with the other group members.

**Figure 6.** Individual progress with GAMA-PGA

The second track of assessments is the more traditional way. The group’s documents are assessed for technical quality and a group mark will be awarded for each document (Requirement Specification, Work Breakdown Structure, Detail Design, Detail Budget, Marketing Plan, etc.)

The final marks are calculated for each student as follows:
(Average of group assignments) X (Relative proportion of GAMAD-PGA) = Final mark

The focus of the assessment process is clearly on the student’s ability to be constantly working through the engineering process to reach the goals of the project. The difficulty of the project does not influence the assessment process. A student can even pass or fail independently of the successful delivery of a working prototype.

**Conclusion**

The aim of teaching Professional Practice 1 is to give the students real practice experience, even before they start with the basic principles of their engineering modules. With this helicopter view on the engineering process; with their experience in documentation quality and control; their exposure to group dynamics and conflict management; and their ability to plan ahead, we believe students are now equipped to cope better with the rest of the engineering programme.

The first students who did this new style of training are now only in their second year of study. The programme is still far from perfect and research to come will clarify the advantage of practice training for students at entry level. An interesting observation in the senior groups, but not scientifically confirmed yet, already shows that students who act as tutors for PP1 clearly stand out in the class. Quality of meetings, quality of documentation and posters, level of group meetings and project planning, peer assessments and conflict management, are clearly on a higher level. If the indirect effects in the faculty are already clearly visible, I can imagine what we will find in two years’ time, when the first group of students reach their final year of study.

**References**


Using Complexity Theory to Develop a New Model of Student Retention

Jonas Forsman¹, Cedric Linder¹², Rachel Moll³ and Duncan Fraser⁴⁵

¹Division of Physics Education Research, Department of Physics and Astronomy, Uppsala University, Sweden, ²Department of Physics, University of the Western Cape, South Africa; ³Faculty of Education, Vancouver Island University, Canada; ⁴Centre for Research in Engineering Education, University of Cape Town, South Africa; ⁵Department of Chemical Engineering, University of Cape Town, South Africa

Jonas.Forsman@fysik.uu.se, Cedric.Linder@fysik.uu.se, Rachel.Moll@viu.ca, Duncan.Fraser@uct.ac.za

Abstract

This paper proposes a new approach to the modeling of student retention in higher education, namely the use of Complexity Thinking, in conjunction with Exploratory Factor Analysis and Multidimensional Scaling. To illustrate our proposal we analyse a small data sample collected from undergraduate engineering students at a highly regarded traditional Swedish university. This analysis shows that issues affecting student retention should be viewed as nested, interconnected systems, in which certain components are more influential than others, rather than in linear terms.

Motivation

Student retention has long been an area of research in higher education. This research has led to models of student retention that are widely used (Bean, 1982; Tinto, 1997). Although “complex” aspects of the relationships between the variables in these models have been acknowledged by many workers in the field, they have not been explicitly incorporated into these models. As a result the existing models are easily interpreted in linear ways. To address this critique we are proposing a different approach to modeling student retention by drawing on complexity thinking as a conceptual framework to develop a new structure for the modeling of student retention. Complexity thinking, when employed in educational research as a conceptual framework (Davis & Sumara, 2006), can identify the structure and dynamics that characterize complex systems, such as the adaptive and decentralized systems of variables that influence student retention.

To illustrate what we are proposing we have used data consisting of questionnaire responses made by Swedish students most of whom were in Masters of Science in Engineering (Physics, and Materials Physics) programmes. We chose this setting context because of international concern over the critical increases in demand for new engineers and scientists, coupled with a decline in interest in careers in science and technology in many countries, particularly in the developed world (CSEPP, 2007; OECD, 2009).

Moreover, in many countries the percentage of students who manage to successfully complete their degree requirements in science and engineering programmes in minimum time, or who graduate at all, is decreasing (CSEPP, 2007; OECD, 2009). In Sweden, for example, the percentage of university students who complete the Master of Science in Engineering degree in minimum time has decreased from 30% to 19% from 1987/8 to 2003/4, and the overall completion rate is also declining (see Figure 1).

The current initiatives and the decline of graduation rates in both the EU and the US, especially in science and engineering, has created a renewed challenge for higher education
institutions to create conditions that are more likely to enhance student progression. It is our aim in this study to develop a model of student retention that will be able to inform such institutions of the most critical features affecting student retention, together with how they are related to one another, so as to better enable them to make holistic decisions with regard to improving retention.

![Figure 1. Percentage of students completing their degree within a set time frame (SSNAHE, 2001 and 2009)](chart)

**Models of Student Retention**

For the purpose of this paper, we start with an overview of the models of student retention and the issues that have driven their development, in order to highlight the importance of introducing complexity thinking into such models. More extensive historical overviews of the field in general are available (Metz, 2004; Summerskill, 1962; Tinto, 1975).

The notion of “complexity”\(^1\) has been apparent in the development of meaningful models of student retention, but it has not been brought to the fore up till now. For example, Spady (1971, p. 38) argues that the formulation of a truly comprehensive model of student retention needs a perspective that “regards the decision to leave a particular social system [studies in higher education] as the result of a complex social process”. More recently Bean (2005, p. 238) has argued that “students’ experiences are complex, and their reasons for departure are complex”.

This brings us to our starting point for the theoretical development for this study. Currently two models of student retention are widely used: The Student Integration Model of Tinto (1975, 1987 and 1997) and The Student Attrition Model of Bean (1980, 1982 and 2005). While these models are seen by some researchers as being two separate systems, we agree with Cabrera et al. (1992a, p. 145) that both “regard persistence [retention] as the result of a complex set of interactions over time.”

Yorke and Longden (2004) describe how the focus of early studies of student retention in higher education were on university structures, such as libraries, schedules, courses and exam

\(^1\)Complexity should not be seen as a synonym for “complicated”, but rather as a characteristic of a system that responds adaptively to stimuli in a way that changes the system itself.
timetables. Subsequently there was a shift in focus towards incorporating a social integration perspective, influenced largely by the work of Spady (1970 and 1971).

The social integration perspective posits that becoming integrated within a social system requires learning the norms, value-systems, and beliefs through interactions within the system. This played a major role in the development of Spady’s theoretical model (1970 and 1971), which sees social integration as a process that encompasses many aspects of students’ everyday lives (such as friendships, family support, the student’s feeling of satisfaction, and the student’s intellectual development). Spady’s model also includes student characteristics such as grade performance, family background, and academic potential. Spady argued that students needed to become a part of the social world of the university if departure rates are to decline.

Tinto (1975) published an expanded version of Spady’s model, which made a distinction between the social system of the university and the academic system. Tinto argued that students also need to become academically integrated to persist in their studies. He posited that some interactions that lead to social integration do not necessarily lead towards integration into the academic system of the university. In Tinto’s conceptual framework the academic system contains the rules, norms and expectations that direct academic life within an institution.

Bean (1980) critiqued Tinto’s model for its lack of external factors, such as economy and housing. The point of departure for Bean’s model was that student attrition should be seen as analogous to work turnover in an employment setting. From this, students’ attitudes and behaviour are shaped by factors such as social experiences, the experience of the quality of the institution, and family approval.

Cabrera et al. (1992a, 1992b and 1993) evaluated Bean’s and Tinto's models by surveying 2453 full-time American freshman students. They found that the two student retention models have common ground and they support each other in explanatory value. The questionnaire they designed was made up of 79 questions, selected from well validated instruments previously used in the field of student retention (see Bean, 1982; Pascarella & Terenzini, 1979).

Eaton and Bean (1995) expanded Bean’s earlier model by adding approach and avoidance behavioural theory, on the basis that students’ experiences shape their individual behavioural approaches towards university life. Some students’ experiences lead towards avoidance behaviour, and some towards an approach behaviour, both of which affect academic integration and thus the students’ intention to leave or stay.

Tinto (1997) then expanded his model by introducing the notion of “internal” and “external” communities that affect student integration into university life. He asserted that within classrooms there are “internal” learning communities where both social and academic systems coexist. The concept of learning communities, together with the presence of “external” communities, opened up new constructs that could help to improve student retention.

Braxton (2000, p. 258) argued that due to the wide variations within the empirical findings associated with Tinto's model, it should be “seriously revised”. Braxton and Lien (2000) compiled empirical results on academic integration and concluded that Tinto’s claim (1975 and 1997) that it is a central construct has not been demonstrated empirically. Braxton and Hirshy (2004) provided empirical data to support their proposal to incorporate three additional factors that may influence social integration: commitment of the institution to
student welfare, institutional integrity, and communal potential. Braxton (2000) suggested that a new foundation for modeling student retention needs to be developed and Tinto himself (2010) argued for the need to develop models that aim towards informing the institutional action of universities.

The next step is then to put forward a modeling system that includes the constructs of the earlier models, can adapt to variations within empirical findings, and empowers universities in their actions toward enhancing student retention. Complexity thinking is a conceptual framework that can help achieve these aims and has the potential to suggest changes to educational practice.

**Conceptual Framework**

In this section, we will present the concepts that we draw upon from complexity thinking to produce a more powerful and holistic modeling system of student retention. As indicated above, the complex nature of student retention has been recognised by the inclusion of a wide set of constructs from different fields of study (such as sociology and psychology) in recent models. What is lacking in dealing with the complexity of student retention is the explicit incorporation of complexity thinking, with its potential as a trans-disciplinary theory that can embrace constructs from a wide array of perspectives and can provide insight into how these constructs interact and influence each other. We will use network theory, exploratory factor analysis and multidimensional scaling to develop a new characterization of the structure and dynamics of the complex system of student retention in higher education.

**Complexity thinking**

Complexity thinking aims to describe and understand complex systems and their capacity to show order, patterns, and structure. Especially important is how these orders, patterns and structures seem to emerge spontaneously from interactions between components of systems. Complexity thinking has emerged and taken root in a wide range of disciplines, generating a theory that essentially “transcends disciplines” (Waldrop, 1992). For more details on the historical development of complexity thinking, see Waldrop (1992), and for an overview of current applications of complexity thinking in a wide array of fields, see Mitchell (2009).

Complexity thinking is often pitted against “classical science”, which is, in turn, portrayed in terms of efforts to condense phenomena into their simplest components. However, to obtain a reasonable portrayal of a complex phenomenon, an understanding of the properties of the components alone is not sufficient. Thus, what is central in describing or understanding a complex system is identifying the components, their interactions, and what emerges from the complex system: system behaviours, properties and structures or the “structuring structures” (Bourdieu, 1984) of the complex system (for example, see Davis & Sumara, 2006).

One can conceptualize the essential aspects of complex systems' structure, dynamics, and predictability through metaphors (for example, see Gilstrap, 2005), computer simulations (for example, see Brown & Eisenhardt, 1997) and systems of modeling (for example, see Mowat & Davis 2010). From this perspective, the essential aspects of complex systems, and what have given rise to complexity thinking’s ubiquitous emergence, are that all complex systems share similar structure and dynamics. Although the behaviour of complex systems such as society, organisms, or the internet can only be conceptually discussed as somewhere in-between complete order and complete disorder, any attempt to measure or distinguish one system as more complex than another often breaks down (Mitchell, 2009). If a system is to be identified as being a complex system what needs to be investigated is the presence of
structures and dynamics that are common among complex systems, not the complexity itself (Davis & Sumara, 2006).

**The structure of complex systems**

Complex systems have *decentralized networked structure*, which means that there are a few components or nodes that are much more connected than others. This kind of structure can be contrasted to two other types of networks: (1) centralized networks with only one central node with every other node only connected to that central node; and, (2) distributed networks where all nodes have the similar connectivity in the network. Information is spread effectively in centralized networks, but they are vulnerable to break down due to the dependency on the central node. On the other hand, distributed networks are robust to break downs but inefficient in spreading information. In the case of decentralized networks, when a highly connected component is removed or breaks down, then the whole system will suffer considerable damage. The system will remain stable, however, with the removal of any of the many less important or less connected nodes.

Due to their decentralized structure, all complex systems are networked with other complex systems. Moreover, components within a complex system can be considered to be complex systems themselves, thus complex systems are *nested*. Nested systems have similar structure and dynamics but operate on different scales (time, size and so forth). For example, mathematics learning-for-teaching has been modelled as several nested systems: subjective understanding, classroom collectivity, curriculum structure, and mathematical objects (Davis & Sumara, 2006). Each level of such nested complex systems exhibits similar structures and dynamics but operates within different time-scales (for example, subjective understanding has a faster rate of change than mathematical objects) and/or at different levels of analysis (such as the level of an individual, or the level of a group of individuals, or the level of a particular culture, or the level of all human beings).

**Dynamics of complex systems**

One key aspect of complex systems is that they are continually changing as the components in the system interact with the external environment and with one another. This means that complex systems are *adaptive* and *self-organize*; properties, behaviour and structure all emerge without an external system or an internal “leader system” that controls the complex system.

Components of complex systems interact mainly locally via *neighbour-interactions*, which can fuel processes that lead to emergence such as positive feedback (brings the system to a non-equilibrium state) or equilibrium through negative feedback. Positive feedback tends to amplify, and negative feedback tends to dampen properties, behaviours and structures. Depending on how “connected” each component is with other components within the system, the positive or negative feedback can be greatly amplified or dampened, which gives rise to the possibility of emergence. Complexity thinking has established that decentralized network structure is a key element in facilitating emergence in complex systems. Through the concept of neighbour-interactions and the decentralized network structure we can argue that nested systems that are highly connected can be seen as close to each other (Davis & Sumara, 2006).

Complexity thinking is not characterized by a particular method but by a methodological perspective that employs a range of methods to study complex phenomena (Davis & Sumara, 2006). Complex systems are networked constellations of components, which in our example are the students’ viewpoints of their experience of higher education in the first year. Each component such as students’ attitudes towards their program and their financial stability, is
considered to emerge from and be situated within multiple complex systems. Analysis of the structure and dynamics of the complex system of students’ retention is possible through, but not constrained to, the following tools used in complexity studies: exploratory factor analysis, multidimensional scaling and network theory.

**Exploratory factor analysis**

Exploratory factor analysis is used to study patterns and order within complex data by comparing angles between points in a multidimensional space. A useful way to view exploratory factor analysis is to see it as essentially what Hofstede et al. (1990, p. 299) has called “ecological factor analysis”; an analysis where the stability of the analysis does “…not depend on the number of aggregate cases but on the number of independent individuals who contributed to each case”.

The components used in the analysis are the retention questionnaire responses plus other student-specific information. Exploratory factor analysis identifies those components that have “commonalities” (Kim & Mueller, 1978) by using the covariance between the components. Components with higher covariance are grouped into a number of factors, with the number being determined by the groupings that arise. Using a complexity thinking perspective, these factors were interpreted as a self-organized pattern of different nested systems, in our case of the complex system of student retention in higher education.

Exploratory factor analysis will normally reveal that some of the components are present in more than one of the factors. From a complexity thinking perspective, this was interpreted as evidence of neighbour interactions between the nested systems through their shared components.

**Multidimensional scaling**

As denoted by the conceptual framework, components of a complex system interact locally (Davis & Sumara, 2006) and thus components that have a high relative closeness to other components in the multidimensional scaling analysis can be regarded as being connected and within each other's “zone of influence”. In the multidimensional scaling analysis of the questionnaire data, the answers and their proximities are used to create a representation of the emergent network structure of the complex system. The components may be seen as vertices connected by edges, which form a basis for visualization and allow for measurements of component interaction through the use of network theory.

A good way to determine the relative proximity of components to one another is to use multidimensional scaling because it offers a way to calculate the distances between points of data in multidimensional space. The relative closeness (“multidimensional proximity”) of components to one another is the “likeness” or “similarities” (Schiffman et al., 1981) of those components.

**Network theory**

The orienting emphasis in network theory is “structural relations” (Knocke & Yang, 2008). From such a framing the essential elements of a network are the nodes (vertices) and the links (connections) between nodes. In the current study, nodes are components examined in the retention questionnaire and data collected from students. Network theory is thus a powerful

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2“Connected” is used as a broad term that encompasses the interaction, communication, and dependence between the different components of the system.
analytic tool to explore and illustrate structure connectivity that was produced using multidimensional scaling.

**Network theory concepts**

The nodes represent the components of a network (i.e. items on the retention questionnaire and student data), and the edges represent the relationships between the nodes. When two nodes are directly connected the two nodes are adjacent. A path is a way through a sequence of nodes that begins with a starting node, follows adjacent nodes through the network and ends at an end. When every node in the network is reachable (i.e., a path exists between every node) the network is connected. If there are many paths between two nodes, the shortest path between them is the one with the fewest connections made through other nodes (Freeman, 1978). Visualization and analysis of networks, and therefore complex systems, is made possible by using these constructs of network theory.

**Network measurements and interpretation**

The network to represent the system of student retention was formed using multidimensional scaling. We assumed that we had an undirected network where the connections between the nodes did not have a specific direction of influence. Analysis of the created network was done by using Statnet (Handcock et al., 2003), a free package designed for analysing networks which works with the “R” statistical computing and graphics program. Identification of “important” nodes was done by calculating each node’s centrality.

In this study we distinguish between closeness centrality and betweenness centrality (Bernardsson 2009). Closeness centrality is an ordinal measure of how “close” every other node is, and it is calculated through finding the shortest path between nodes. Information can be spread to the whole network more effectively via nodes with high closeness centrality (Freeman, 1978). Betweenness centrality is the frequency that one particular node is a part of the shortest path between every other node. Nodes that are more frequently a part of the shortest path between nodes may be interpreted as having a high degree of “control of communication” (Freeman, 1978, p. 224) in the network.

**Method**

Data was collected from two sources: firstly student records were used to obtain student demographic information such as age, gender, higher education credits achieved within and outside the programme, and student retention, and secondly, a questionnaire with 29 questions was developed to explore influences on student retention. The questionnaire was largely based on the work of Cabrera et al. (1992a, 1992b and 1993). Students answering the questionnaire were asked to mark their level of agreement (or disagreement) with 29 statements on a five-point Likert scale. Each separate piece of information (record data and question responses) was an item in the analyses, giving 34 items altogether.

As a preliminary study to verify our approach, the questionnaire was administered to 51 students (39 of whom were in two Engineering Programmes, and the remaining 12 in a Physics Programme) participating in a second semester Physics course at a traditional Swedish university. Re-enrolment in the second year (third semester) was used as a measurement of student retention and was found to be 82.4%.

**Results**

Firstly, exploratory factor analysis was used to identify subsidiary complex systems within the broader complex system, and to demonstrate their nested structure. Secondly,
multidimensional scaling was used to show the connectedness of the components and to visualize how the components of the complex system interact with one another.

Exploratory factor analysis showed the subsidiary systems that are nested within the larger complex system of student retention. Four sub-systems were identified, with some items that overlapped between them, which demonstrated the nestedness of the sub-systems. Other items dropped out altogether.

This pilot study was too small to draw any conclusions about the nature of these four sub-systems, which appear to correspond to different levels of analysis of the whole complex system such as the level of the individual student, the level of groups of students, the level of the institution, etc. It is tempting to try to match these sub-systems with the systems identified earlier, such as the internal social and academic systems and the external system proposed by Tinto (1997), but we believe that this would tend to limit what could emerge from an analysis such as this one.

**Exploratory Factor Analysis**

Having satisfied ourselves that we had data items grounded in the literature we started with an exploratory factor analysis. This was to identify the complex systems that make up the greater system of student retention through the identification of the factors within the overall system. Our analytical tool was the Statistical Package for the Social Sciences, SPSS (Predictive Analytic SoftWare, PASW, version 18.0). Our starting point was the normalized matrix of the questionnaire data together with the students’ higher education credits achieved within and outside their programme, retention (re-enrolment in the second year), age, and gender.

The following three measures were used together to achieve an appropriate correlation matrix of items to be used for exploratory factor analysis (Dziuban & Shirkey, 1974):

1. Kaiser-Meyer-Olkin's (KMO) measure of sampling adequacy. Items were removed recursively from the data until a value of 0.68 was obtained, close to the guideline 0.7 recommended by Kaiser & Rice (1974).

2. Bartlett's (1950) test of sphericity. This had a significance of less than 0.001 when guideline 1 had been achieved.

3. The anti-image correlation measure of sampling adequacy (MSA). Items with an MSA less than 0.5 were removed (Kaiser, 1970).

As a result, eleven items (of a total of 34) were removed and are listed in Table 1. These items were interpreted as having little effect on the system of student retention, at least as far as this illustrative study is concerned, given the limited data set and the high level of retention from first year to second year.

In deciding the number of factors in the model we used a scree test (see scree plot in Figure 2). “The scree test involves examining the graph of the eigenvalues … and looking for the natural bend or break point in the data where the curve flattens out. The number of data points above the 'break' ... is usually the number of factors to retain” (Costello, 2005, p. 3). Every item is treated as a vector that has an eigenvalue of 1.0 before the iterative rotations and calculation of vector projection on an axis. An eigenvalue of 7 (One Factor) provides us with the information that all significant loadings in One Factor can be grouped, providing us with 7 times as much information as a single variable and also that the items in the factor share traits.
This led us to choose a Four Factor solution for the model (Hofstede, 2001). The cut-off at Four Factors, and not Five (although they have nearly the same eigenvalue) was guided by seeing that a Five Factor solution provided one factor with only two variables that had significant loading (more than 0.32) which according to the analysis-method is not appropriate for such a factor solution. The "extra" factor wouldn't give much more information than adding one or two other variables to the analysis or the questionnaire.

**Table 1. Items removed from the Exploratory Factor Analysis**

<table>
<thead>
<tr>
<th>Question</th>
<th>Item</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Age.</td>
<td></td>
</tr>
<tr>
<td>- Gender.</td>
<td></td>
</tr>
<tr>
<td>- Credits passed that are not a part of the programme of study.</td>
<td></td>
</tr>
<tr>
<td>6 My possibility to continue with my studies is dependent on me working while I study.</td>
<td></td>
</tr>
<tr>
<td>9 It is important for me to graduate at my University.</td>
<td></td>
</tr>
<tr>
<td>13 I have achieved the study-results I expected during the first year.</td>
<td></td>
</tr>
<tr>
<td>18 It is important for me to get a university degree.</td>
<td></td>
</tr>
<tr>
<td>20 I have developed a good relationship with my teachers in the courses I have studied.</td>
<td></td>
</tr>
<tr>
<td>26 First year physics courses have been inspiring.</td>
<td></td>
</tr>
<tr>
<td>27 University physics courses are much different from my previous physics courses.</td>
<td></td>
</tr>
<tr>
<td>28 First year physics courses have had a clear connection to everyday life.</td>
<td></td>
</tr>
</tbody>
</table>

Significant item loadings for each factor were identified by using a minimum loading of 0.32 on each item, which corresponds to a 10% shared variance between items (Tabachnick & Fidell, 2001). Question 12 was retained at a loading of 0.313 (which is very close to 0.32).

The results of the exploratory factor analysis are shown in Table 2. Note that these results differ from the normal result in exploratory factor analysis where unique variables are sought for each factor. It is tempting to try to characterize the four factors in terms of the systems identified by others (such as university academic systems and social systems (Tinto, 1975) and support systems (Bean, 1980)) but this cannot be done because of the small sample size. What Table 2 does show is that there is overlap of items between the four factors, each of which is a complex system in itself. This illustrates both the complexity and the nestedness
of the system of student retention as a whole. It also highlights the existence of neighbour interactions between the four nested systems, as well as the fact that they have fuzzy boundaries.

We can only provide a very tentative characterization of these four factors, due to the small sample used in the analysis. The items with the highest loadings in Factor 1 have to do with the status of the programme the students are studying. Factor 2 seems to be characterized by a sense of belonging. It is hard to find any strong theme in Factor 3 which has particularly fuzzy boundaries with Factor 2. Financial issues clearly dominate Factor 4. One might therefore identify Factor 2 as pertaining to the individual student, Factor 1 with the institution and Factor 4 with the external system, but note the comments in this regard at the start of the Results section.

Table 2. Loading from the exploratory factor analysis (factors sorted adjacently by shared items).

<table>
<thead>
<tr>
<th>Item</th>
<th>Factor 1</th>
<th>Factor 2</th>
<th>Factor 3</th>
<th>Factor 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>H.E. credits within programme (HECwP)</td>
<td></td>
<td>0.542</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Retention</td>
<td></td>
<td>0.934</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q1. Best university programme</td>
<td>0.788</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q2. Family approval</td>
<td></td>
<td>0.472</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q3. Satisfied with finances</td>
<td></td>
<td></td>
<td></td>
<td>0.836</td>
</tr>
<tr>
<td>Q4. Finances - focus on studies</td>
<td></td>
<td></td>
<td>0.833</td>
<td></td>
</tr>
<tr>
<td>Q5. Finances - teacher demands</td>
<td></td>
<td></td>
<td></td>
<td>0.796</td>
</tr>
<tr>
<td>Q7. Satisfied with curriculum</td>
<td>0.328</td>
<td>0.458</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q8. Close friends encouragement</td>
<td></td>
<td>0.580</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q10. I belong at my university</td>
<td>0.637</td>
<td>0.447</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q11. Future employment</td>
<td>0.464</td>
<td>0.390</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q12. My close friends rate this institution as high quality</td>
<td></td>
<td></td>
<td>0.313</td>
<td></td>
</tr>
<tr>
<td>Q14. Satisfied with experience of higher education</td>
<td>0.687</td>
<td>0.411</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q15. Easy to make new friends.</td>
<td></td>
<td>0.842</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q16. Right choice - university</td>
<td>0.683</td>
<td>0.399</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q17. Right choice - programme</td>
<td>0.758</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q19. It is important to get a degree from this programme</td>
<td>0.708</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q21. Initiation weeks</td>
<td></td>
<td>0.855</td>
<td></td>
<td>0.459</td>
</tr>
<tr>
<td>Q22. First year courses fit together</td>
<td></td>
<td></td>
<td></td>
<td>0.385</td>
</tr>
<tr>
<td>Q23. Previous knowledge</td>
<td>0.385</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q24. Clear educational trajectory</td>
<td>0.447</td>
<td>0.396</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Q25. Faculty support</td>
<td>0.345</td>
<td>0.322</td>
<td>0.461</td>
<td></td>
</tr>
<tr>
<td>Q29. I intend to re-enroll</td>
<td>0.835</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note: Light grey shading denotes the items that have a loading above 0.32 in more than one factor.

Multidimensional scaling

Multidimensional scaling was used to visualize the network of items that influence student retention (using the same 34 items that were used for the Exploratory Factor Analysis). Network theory data analysis tools and complexity thinking were used to interpret the results.

Network Creation

The multidimensional scaling analysis was used on the data to determine the distances between items arising from this data. A dimensional solution ranging from two to four
dimensions was explored, because multidimensional scaling usually provides a solution that has fewer dimensions than exploratory factor analysis on the same data (Schiffman et al., 1981). The multidimensional scaling analysis converged to a solution after 15 iterations. Figure 3 shows the resulting visualization of the network.

Note how in Figure 3 the items that are less connected (and hence less important) are on the periphery, whereas the more central items clearly lie on the paths between many other items and are thus more significant to the operation of the network.

We used the multidimensional proximities between the items to identify items with relative closeness or proximity. Using the neighbour-interactions concept and an understanding of the structure of decentralized networks (Davis & Sumara, 2006) from complexity thinking, we recursively lowered the cut-off for proximities and network visualizations were produced. The statistical computing and graphics “R” program, together with Statnet package (Handcock et al., 2003), were used for visualization and measurements. Iterations were run as long as the network continued to resemble a decentralized network, but were ended before the network broke down and ceased to be connected (Freeman, 1978).

Two items were considered to be within each others’ “zone of influence” when their proximity was below 0.25. The analysis was complete when the majority of the items had proximities less than 0.25. To retain the connectedness of the system Retention needed to have a higher cut-off of 0.5. HEPoP, Gender Q6 (studies dependent on working) and Q9 (importance of achieving a degree from this university) all dropped out at this cut-off level. These items are four of the eleven items that were dropped from the Exploratory Factor Analysis.

Note that as the cut-off level is lowered further the system becomes less and less connected. At a cut-off proximity of 0.1 less than half the items remain connected to one another.

Multidimensional scaling was used to calculate the proximities between items pertaining to student retention and these were visualized in a 2-D network. The network was found to be decentralized in structure. Three items that were clearly outliers from multidimensional scaling were also items that dropped out of the exploratory factor analysis. However, not all items that were dropped in the exploratory factor analysis were loosely connected in the
network. Moreover, three particularly influential items (nodes) were identified. These three items were each present in two of four factors in the exploratory factor analysis.

**Influential items**

In this study we distinguish between *closeness centrality* and *betweenness centrality* (Bernhardsson 2009). Closeness centrality is an ordinal measure of how ‘close’ every other node is, and it is calculated through finding the shortest path between nodes. Information can be spread to the whole network more effectively from nodes with high closeness centrality (Freeman 1978). Betweenness centrality is the frequency that one particular node is a part of the shortest path between every other node. Nodes that are more frequently a part of the shortest path between nodes may be interpreted as having a high degree of ‘control of communication’ (Freeman 1978, p. 224) in the network.

We used the *closeness centrality* and *betweenness centrality* scatter plot (Figure 4) to identify network items (nodes) that have a larger influence in the network. Nodes with high *closeness centrality* and high *betweenness centrality* both distribute information effectively to a large proportion of the system, and are in a position of “control” of other nodes’ influences on the system. Figure 4 shows nodes that are “close” to other nodes and nodes which have a high frequency of being “between” other nodes.

Consideration of Figure 4 shows that there are seven items with relatively high betweenness centrality as well as relatively high closeness centrality: Q12 (friends’ opinion of institutional quality), Q7 (satisfaction with one’s course curriculum), Q25 (faculty support), Age of the students, Q14 (students’ satisfaction of being at the university), Q10 (the feeling of belonging at the university), and Q28 (physics is connected to everyday life). Item Q25 (faculty support) is interesting in that it seems to lie outside the broad band of points showing higher betweenness centrality vs higher Closeness centrality: It has a much higher betweenness centrality than the rest of the items in the band. The same is also true for Item Q24 (clear educational trajectory). Connections between exploratory factor analysis results and multidimensional scaling results will be discussed below.

![Figure 4. Closeness centrality and Betweenness centrality scatter plot of the network created by the Multidimensional Scaling analysis proximities of items.](image-url)
Discussion

This pilot study was too small to draw any conclusions about the nature of the four sub-systems identified through exploratory factor analysis. It is tempting to try to match these sub-systems with systems previously identified, such as the internal university academic, social, and support systems and the external system (Bean, 1980; Tinto, 1975 and 1987), but we believe that this would tend to limit what could emerge from an analysis such as this one.

From multidimensional scaling and the visualisation of the network shown in Figure 3, it is clear that this is a decentralized network. The three most influential components were each present in two of four factors in the exploratory factor analysis. The four components that dropped out of the multidimensional scaling and three of the outliers were among the eleven components that were dropped from the exploratory factor analysis. Thus both sets of analyses produce congruent results.

Conclusions

What is new in our example is that we were able to identify certain items as influencing the complex system as a whole. This means that they should not be seen as direct linear influences, but as influences mainly through other items. This implies that things are more interconnected than previously acknowledged in student retention. In this way, these items, their emergent patterns, and their interactions, combine to form a dynamic model of student retention with nested sub-systems.

While some previous researchers have acknowledged the complex nature of interactions of elements relevant to student retention, our analytic example shows how the structure and dynamics of the complex systems that influence retention can be brought to the fore empirically. We would suggest that it is unlikely that either faculty or students are aware of the extent of the complexity that underpins how student retention emerges as a result of the complex interaction between the components of the nested systems. In our modeling, the higher education experience is shown to have its greatest influence manifested through the complex dynamics of these different nested systems. This is in stark contrast to linear thinking about the experience of higher education and it can provide insight into how to better manage it to improve student retention.

For this work to be more meaningful it will clearly need to be extended to a much larger data sample in which retention is determined over a longer time frame. It will also need to be triangulated with more in-depth qualitative studies. This preliminary study has shown the potential of this approach to modeling student retention to uncover a much deeper insight into student retention in programmes such as engineering and thus inform institutional actions aimed at improving retention.

References


Acknowledgements
We would also like to thank Staffan Andersson, Jannika Chronholm-Andersson and Anne Linder for the very rewarding discussions throughout the development of this paper.

Appendix: Questionnaire
Q1. I am studying one of the best programmes at the university.
Q2. My family approves of my attending my University.
Q3. I am satisfied with my financial situation.
Q4. My financial situation allows me to focus on my studies as much as I want.
Q5. My financial situation allows me to focus on my studies as much as the teachers demand.
Q6. My possibility to continue with my studies is dependent on me working while I study.
Q7. I am satisfied with my course curriculum.
Q8. My close friends encourage me to continue attending my University.
Q9. It is very important for me to graduate at my University.
Q10. I feel I belong at my University.
Q11. My degree at this university will help me secure future employment.
Q12. My close friends rate this university as a high quality institution.
Q13. I have achieved the study-results I expected during the first year.
Q14. I am satisfied with my experience of H.E.
Q15. It has been easy for me to meet and make friends with other students at this university.
Q16. I am confident I made the right decision in choosing to attend at my university.
Q17. I was right when choosing to study this programme.
Q18. It is important for me to get a university degree.
Q19. It is important for me to get a degree from this particular programme.
Q20. I have developed a good relationship with my teachers in the courses I have studied.
Q21. The initiation weeks were a good start for my program studies.
Q22. It is clear to me how the courses during the first year fit together.
Q23. The teaching has corresponded well with my previous knowledge.
Q24. My educational trajectory is clear for me.
Q25. Faculty staff have provided me with the support I needed to succeed in my studies.
Q26. First year physics courses have been inspiring.
Q27. University physics courses are much different from my previous physics courses.
Q28. First year physics courses have had a clear connection to everyday life.
Q29. I will re-enrol at this programme of study next autumn.
Building a More Responsive Curriculum in Chemical Engineering at the University of Cape Town

Duncan Fraser¹ ², Jenni Case¹ ², Hilton Heydenrych² and Eric van Steen²
¹Centre for Research in Engineering Education, University of Cape Town, South Africa; ²Department of Chemical Engineering, University of Cape Town, South Africa
Duncan.Fraser@uct.ac.za, Jenni.Case@uct.ac.za, Hilton.Heydenrych@uct.ac.za, Eric.vanSteen@uct.ac.za

Abstract

This paper describes the re-structuring of the chemical engineering curriculum at the University of Cape Town, in order to respond both to a changing student population as well as the changing world of work. The basis for the changes proposed was an analysis of problems within the existing curriculum. The changes are based on educational research, particularly as it pertains to quality student learning, as well as models of curriculum innovation at other reputable institutions. Key features of the new curriculum are discussed.

Introduction

Poor throughput of engineering graduates together with declining interest in studying for engineering are being experienced in most of the developed world, particularly in Europe (CSEPP, 2007; OECD, 2009). South Africa shares the problem of poor throughput but is fortunate in that there is a strong interest in engineering in South Africa at present, in common with other developing countries.

What we also share with many other countries is an increase in students from different backgrounds entering engineering programmes. In the case of South Africa this is much more extensive than elsewhere, in that the majority of the population (black students who were excluded from studying engineering in South Africa under the previous apartheid regime) now form the bulk of students in most engineering programmes.

In the Department of Chemical Engineering at the University of Cape Town (UCT) we have been grappling over the last 25 years with the increasing diversity of students in our programme., and in particular with the much poorer success of black students. This process is described in more detail in the next section, leading to a decision to develop a completely new decision.

In this paper we will focus on the principles that have guided us in developing our new curriculum, the processes we have followed in doing this, the particular problems we have sought to address, and the new curriculum structure and approach to teaching and learning and assessment that have resulted. We will also relate all these as much as possible to international developments so that it is relevant to those in other countries. But first we will briefly describe our context to provide an understanding of where we are coming from.

Context

The legacy of apartheid schooling in South Africa is still felt strongly today, despite efforts since 1994 to improve the situation. As a result, most of the black students entering our programme are disadvantaged educationally to a greater or lesser extent, despite meeting our high entrance criteria. The major response of South African universities to this issue has been in the establishment and development of academic support programmes (Kloot, et al.,
While these programmes have undoubtedly given opportunities to many students that they might not otherwise have had, they also bring with them a number of difficulties for the students. These include moving through the programme at a different rate to students on the regular programme (and thus having a less coherent experience of the programme and also not being part of the regular class who move through the programme together), and the experience of stigma (cf. Tema, 1988). This is not dissimilar to the experience of students who enter through the mainstream but who by failing courses along the way end up losing their class, having an incoherent curriculum experience, and also dealing with loss of self esteem.

At the outset we need to note that UCT Chemical Engineering graduates are generally well-received by traditional industrial employers, and our industrial partners are enthusiastic about the kind of programme we offer. We consider these favourable responses as a baseline from which we can improve the educational experience that we offer students.

As far as throughput is concerned, two analyses have been completed, one for the cohorts entering between 1988 and 1998, and the other for the cohorts between 2001 and 2005 (see Table 1). These data show marked improvement in the success of the first year intake across all racial categories and in aggregate. Nonetheless there is still significant variability across the demographic groups, and there remains scope for improvement.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Black African</td>
<td>40%</td>
<td>67%</td>
</tr>
<tr>
<td>Coloured</td>
<td>49%</td>
<td>68%</td>
</tr>
<tr>
<td>Indian</td>
<td>36%</td>
<td>57%</td>
</tr>
<tr>
<td>White</td>
<td>66%</td>
<td>84%</td>
</tr>
<tr>
<td>International*</td>
<td>-</td>
<td>65%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>57%</strong></td>
<td><strong>70%</strong></td>
</tr>
</tbody>
</table>

* In the 1988-1998 data international students were grouped in the South African race categories; with the majority of them counted as Black African.

In conjunction with poor throughputs rates, we also have many students taking longer than the minimum time to complete their degrees. This is particularly so for black students, for whom the average time to graduation is one year longer on average than for white students.

In the early 1990s the Engineering Faculty embarked on a process of curriculum development that was led by a small task team. The motivation for this process was three-fold: to reduce student overload (already recognised then as a world-wide problem (Sheahan & White, 1990; Swaim & Moretti, 1991)), the changing student body (notably the increasing proportion of black students from disadvantaged educational backgrounds) and the changing engineering workplace. The new Engineering curriculum was rolled out from 1995 onwards, with the major changes being in first and second year. This resulted in the introduction of Engineering I courses, and reduced content in the common first year Physics and first and second year Mathematics courses, but not much beyond that.

Since then the Chemical Engineering Department has continued to make some structural curriculum changes as well as a number of significant educational innovations. The courses in the first semester of fourth year are now strongly project-based, with certain weeks being devoted to intensive focus on particular projects. The second year industrial field trip takes
the second year class to an industrial site where they perform a range of exercises over a period of a week. The first year camp aims to break down barriers and build community in the first year class.

Problems

An ongoing programme of educational research in the department, together with regular engagements with our undergraduate students has led to a consolidated view of some of the key problems with our existing curriculum. These can be summarised as follows:

Workload

Our early studies of students’ approaches to learning in second year pointed to excessive content overload as a major factor which mitigates against students being able to adopt a necessary ‘deep’ approach to learning (Case 2007). This was further confirmed in a study of third year students which linked this level of workload to a state described as ‘alienation’ (Case & Gunstone, 2002). In informal discussions with students it is clear that the time students spend on our courses typically exceeds the notional credit rating for these courses (10 hours per credit); with this in mind it is also worth noting that even the notional credits (588) exceed those required by the Engineering Council of South Africa (ECSA) (560). At UCT students also have a very short working year, with only 24 weeks of contact time and 6 weeks of study/examination time, leaving 22 weeks in the year unused for academic work.

Coherence and integration

The current four year curriculum does not achieve good vertical integration in the areas of computing, teamwork and writing, with a lack of sustained progression in developing student competence in these skills. In-course curriculum development over the years has not yielded significant improvements in these areas.

For the majority of graduates who take more than four years to complete the degree there are additional levels of incoherence with longer than planned gaps between related offerings of core content.

There is also a deeper problem with regard to integration, namely the difficulties students have when required to integrate knowledge from different subject areas and courses. This extends from application of scientific and mathematical knowledge in chemical engineering to integration of knowledge from a range of chemical engineering subjects in design.

Teaching and assessment modes

Students’ abilities to cope with the exit level assessments at fourth year has raised issues about whether teaching and assessment at the earlier levels provides adequate preparation (cf. Kotta, 2008). In particular, some students have struggled to produce the integrated thinking that is demanded at exit level. A related matter is students’ abilities to be independent and creative thinkers. This can be traced at least in part to teaching modes in the earlier years which can be characterised as focusing on transmission of content and convergent problem solving. Furthermore, the observation that some final years appear to be struggling with relatively basic knowledge suggests that these teaching and assessment modes are not even succeeding at instilling the basics.

Opportunities for specialisation

The existing curriculum has very minimal opportunities for students to choose specialised courses that they are particularly interested in: optional electives constitute only 48 out of a total of 588 credits. This seems out of step with trends elsewhere in higher education
especially in engineering, and seems a lost opportunity to promote student motivation through choice.

**Relevance**

Concerns about relevance function at two levels. The first concerns the current career destinations of the majority of our graduates to the process industries. We have had ongoing concerns about students’ awareness of chemical engineering practicalities in the real world, for example in being able to visualise the size of units. This has been at least partly addressed with the introduction of the second year field trip. The second level where relevance has been raised concerns the possible future career destinations for our graduates. The profession is changing rapidly as the world faces unprecedented challenges in the areas of resource and energy provision, and this would seem to demand changes in the orientation of the curriculum (IChemE, 2007).

**Motivation**

Building on the above, two themes can be identified which form the underlying motivation for a renewal of our curriculum. The first concerns a view on the kind of student learning experience we would like to offer, and the second concerns a view on the kind of chemical engineering graduates we would like to produce.

**Student learning**

Over a long and sustained period of time the department has exercised a serious interest in the quality of student learning in the programme. This has led to educational research being conducted, which has been enhanced through the sponsorship by Caltex of an Educational Development Officer post in 1994, plus another post like this initiated by XStrata in 2005 and further supported by funds from the Department of Education.

We now have nearly two decades of educational research conducted with our students, and we thus have some relatively clear ideas of the kinds of student learning that are desirable in the programme and what teaching and curricular arrangements are needed to support this.

Our early work focused on students’ understanding of key chemical engineering concepts, and we were able to identify factors that mitigated against students’ adopting a deep approach to learning, such as a high workload and perceptions of time pressure. A related perspective which we have developed is that our overloaded curriculum doesn’t adequately distinguish between basic fundamental concepts and advanced applications. Students in attempting to grapple with this broad coverage appear to get caught up in technically advanced problems while lacking the underlying basics.

The data from these early studies however also pointed to broader issues that were pertinent, including students’ wider world of home, student life and career aspirations (Case, in preparation). Later studies thus focused on students’ degrees of engagement with not only the programme but also the career (Case, 2007) and looked at coping strategies drawn from broader student and home life which were productive for facilitating quality learning (Case & Fraser, 2002).

A useful framework summarising the key elements of this perspective on student learning is provided by Barnett and Coate (2005) who argue that in addition to a traditional focus on knowledge and skills (characterised by them as a focus on ‘knowing’ and ‘acting’) we need to enlarge our viewpoint to include a development of students’ ‘being’.
Work has also been done on the use of simulations to enhance student learning (Fraser, 2009; Streicher, et al., 2005), the use of variation to enhance student learning (Fraser & Linder, 2009; Fraser, et al., 2006), and the use of Problem-Based Learning (Fraser, 2009).

We are thus in a special position as a chemical engineering department in that we have in-house educational scholarship which has generated a contextually nuanced perspective on quality student learning and how we might promote it. Small scale recommendations from this research have been implemented in individual courses over the years but it has also been made clear that only limited gains can be made in single courses (Case & Gunstone, 2006) and thus a full scale curriculum renewal is desirable at this stage.

The chemical engineering discipline and profession

The UCT chemical engineering curriculum reflects a typical 20th century offering in the discipline, focused quite strongly towards the large scale chemical and petrochemical industries. Currently it appears that roughly 2/3 of our graduates head to these industries, starting with technical experience after which many move into management roles. Most of the remainder of the class go directly to careers in finance or business.

With regard to the changing industrial landscape in the light of concerns about environmental and social sustainability, nearly all our students cite a strong interest in these concerns although as yet there are not many careers for chemical engineers that look all that different to those of the previous century.

The UK-based Institution of Chemical Engineers (IChemE) recently undertook an extensive consultative process with members all around the world to map out the future directions for the profession. This process delivered a ‘road map’ which lays out key foci for future work (IChemE, 2007). These are:

1. Sustainability and Sustainable Chemical Technology
2. Health, Safety, Environment and Public Perception of Risk
3. Energy – Securing Reliable and Affordable Supplies
4. Food and Drink
5. Bioprocess and Biosystems
6. Water Engineering

This framework forms a useful basis for thinking through future directions for the discipline, the profession and the work that our future graduates should be equipped to do. The task at hand is to deliver a curriculum that is sensitive to the future yet keeps step with current demands.

A related matter is the ongoing shift in developed world contexts towards the ‘knowledge economy’. Companies increasingly are competitive on the basis of the intellectual capital of their employees, and on an individual level this can’t be seen as a static amount that a graduate presents only on the basis of formal qualifications, but rather a lifelong process of learning and development. These kinds of trends are of course congruent with the overall orientation of higher education institutions, focused primarily on knowledge. Although the academic activities of research and teaching have sometimes been portrayed as in opposition to each other, a more productive orientation looks to strengthen the links between these domains, and thus a question of what ‘research-led teaching’ might be has arisen in many quarters, including at UCT. In the context of preparing graduates for the ‘knowledge
economy’ this appears to be a direction worth pursuing, given also the way the chemical engineering discipline which needs increasingly to focus towards an unknown future.

**Objectives**

On the basis of the above, we have decided that we will adopt the following quantitative objectives in terms of our intake and overall success for the new curriculum:

1. Maintain the existing target intake of 120 students, as well as the current demographic spread.
2. Improve overall success rate from 70% to 83% (in order to deliver 100 graduates off an intake of 120). From the racially disaggregated statistics it can see that this implies bringing the success rates of black students in line with those of white students (already at 84%).

The new curriculum will have the structure, teaching and learning approaches, and resources to deliver on these objectives.

**Process**

During discussions in 2007-8 it was decided that some sort of review was desirable. Towards end of 2008 it was decided that a full renewal was preferable to an upgrade involving some tinkering of the programme and fixing up obvious problems.

A helpful perspective on how to tackle curriculum renewal is provided by Toohey (1999), summarised in Figure 1. From this diagram it is clear that an important starting point is establishing the beliefs and values that will underpin the new programme, as well as the broader goals that are intended. Following this the structure of the programme can be decided on, as well as the content to be taught. Final considerations are entry criteria and resource implications. This discussion document thus follows Toohey’s logic, beginning with a clarification of the motives for undertaking a curriculum renewal, followed by an outline of the intended programme structure.

A small team within the department has worked over the past two years to formulate the new curriculum. These developments have been presented to the whole staff team at workshops every six months. In these workshops we have obtained buy-in on a range of important features of the new curriculum: the motivation for change, the overall structure, the core content (which involved reduction in the core content), and more detailed fleshing out of how the content will be delivered.

**International developments**

An important part of our curriculum renewal process has been to engage with international developments, both in terms of traditional offerings elsewhere, as well as new developments.

We have noted with interest the motivations that have been put forward for curriculum renewal in chemical engineering in other parts of the world. All the work that we have surveyed takes as a departure point the changing requirements of the profession. A key difference is that many first world contexts cite a declining interest in chemical engineering as a reason for revitalising their programmes, to attract good students.

Given the origins of our education system, it is not surprising that the UK and Australasia have degree structures that are most comparable to ours, and which have offered the most useful models for rethinking our curriculum. In this regard we have focused on the innovative curriculum reforms at Imperial College, University of Sydney and University of
Queensland. These are research-intensive institutions similar to what UCT, whose curriculum reforms are examined in some detail below.

As far as Europe is concerned, the Bologna process led the European Federation of Chemical Engineering (EFCE) to run an extensive project to document chemical engineering programme offerings across Europe, in order to reach some agreement on content. This work took place against the backdrop of chemical engineering as a discipline having to adapt to changing contextual demands such as outlined earlier. There was also a concern about declining student interest in chemical engineering.

The Working Party on Education (WPE) of the EFCE, in an extensive consultative process, reached agreement on a few basic departure points for chemical engineering curricula (Gillett, 2001). It was agreed that the first degree should focus on the basics, with a particular emphasis on systems thinking, and that specialisation should take place in graduate studies. It was suggested that curricula should be structured under the headings of basic science, engineering core, and electives. Electives were the spaces where academics could teach advanced material based on their research interests. The WPE defined a common ‘core’ which would occupy roughly 50% of the time; this has formed a useful resource for benchmarking of our curriculum content.

Engineering education reform in North America has been less focused on content and more oriented towards broader graduate attributes. A system of ‘Coalitions’ of institutions was established in the 1990s. These were at the forefront of developing novel programme arrangements and pedagogies to develop teamwork, multi-disciplinarity, communication skills, and so on. Problem-based learning (PBL) and related innovations centred around ‘real world’ problems have been central. PBL in Engineering was pioneered over twenty years ago in the Chemical Engineering Department at McMaster University in Canada by Donald Toohey, 1999).

Figure 1. Outline of the curriculum renewal process (from Toohey, 1999).
Woods. A key objective of most of this reform is aimed at increasing the participation of women and minorities in engineering.

Key developments in the three institutions identified earlier will be outlined in the sections that follow:

**Imperial College**

Imperial College offers a four year programme leading to the degree of Master of Engineering (M.Eng). The programme involves chemical engineering from the first year of study. There is an intensive use of project work throughout the curriculum, with lectures and tutorials typically confined to the mornings and design-oriented project work on all except one ‘free’ afternoon. In 1995 they introduced ‘mastery’ assessment, whereby students need to demonstrate 80% proficiency on tests of what are considered the essentials of chemical engineering. To progress to the following year, students need to pass with 40% separately in coursework and examinations in each course. Borderline candidates are given supplementary examinations in up to two subjects. The last two years of the course offer a range of different directions for students depending on the interests they have developed.

The curriculum is structured under the ‘outcome’ headings of knowledge and understanding, intellectual (thinking) skills, subject practical skills and key/transferable skills. The first category contains much of the usual ‘content’ for a chemical engineering curriculum, with a relatively strong focus on systems engineering (Perkins, 2002). It also includes management and humanities options. The second category deals with the intellectual skills needed for analysis, synthesis (design) and research. The third category deals with practical skills for experimental work, as well as computational packages. The final category encapsulates oral and written presentations, team work, as well as broader professional issues.

**University of Sydney**

The School of Chemical and Biomolecular Engineering at the University of Sydney offers a four year degree leading to a qualification which is accredited by the IChemE as equivalent to the M.Eng degree. A complete overhaul was undertaken in response to a perception that their graduates lacked the competencies required in the workplace, especially an ‘adaptive flexibility’ needed as so many of them no longer went to the traditional process industries. It was felt that the semesterized curriculum with knowledge in different compartments was playing a strong role in this problem.

The new curriculum is structured around a problem-based learning approach, emphasizing competency attainment, and involving strong horizontal and vertical integration. Courses were designed that fitted into the following categories, with each semester containing all these course types: core principles (presenting fundamental chemical engineering concepts), enabling technology (tools, often computer-based, needed to solve problems), engineering practice (Core Practice courses) and electives (either specialised or broadening).

All of these courses are offered in PBL mode. The course structures do not reflect the traditional chemical engineering science categories related to unit operations. There are no dedicated mathematics courses after first year; any mathematics needed is taught in the context of the relevant chemical engineering course. An input into the design of these courses was the ‘deconstruction’ of the old curriculum, assigning each aspect that was retained to one of these categories.

In years 2 and 3 of the programme, assessment of the core and enabling courses is via ‘competency’ assessment (similar to the ‘mastery assessment’ at Imperial College) and
students are simply awarded pass/fail results. Assessment of competency is through a range of course assessments as well as the final examination. Because of the tight integration in the programme, student progression through the programme is largely ‘plug flow’ in nature, with only one uncompleted course being able to be carried into a subsequent year. Supplementary oral examinations are conducted with borderline candidates in order to keep as many students as possible in the planned curriculum.

University of Queensland

The University of Queensland implemented in 2001 what they term a ‘project-centred’ curriculum in their four year undergraduate chemical engineering programme. Similarly to the University of Sydney, they motivate these changes on the basis of changing demands on their graduates in the workplace, especially in terms of aspects such as teamwork and communication needed in multidisciplinary work contexts. Curriculum change was thus founded on an establishment of desirable graduate attributes or outcomes (this was also a key part of the Sydney process).

Their curriculum was built around a ‘spine’ of project work that runs through all years of the programme. Each semester has one compulsory course that is ‘project-centred’. Projects are built on simulated real world problems and run over 6-13 weeks, with students working in groups of 4-6. They note that these courses have been particularly well received by students. Similar to Sydney they have a common engineering first year, with chemical engineering proper starting in the second year of the programme. The chemical engineering core is structured fairly traditionally in terms of the major topics in chemical engineering science. Elective courses run through each year of the programme.

New UCT curriculum

The following are key design features of the new curriculum:

1. Building a strong learning community, with the majority of the students staying together from year to year.
2. Integration of academic development with the regular programme, both through all the teaching in the programme, and through the use portions of the winter and summer breaks for students to master areas of difficulty.
3. Increased focus on mathematics to allow the time necessary to build on the current school mathematics foundation. There is a particular challenge for us here with recent changes in the school maths syllabus.
4. Active learning of chemical engineering theory and practice in a ‘homeroom’.
5. Assessment that involves regular feedback and a particular focus on mastery of the fundamentals.
6. Separation of fundamentals from practice, with each being assessed differently, but with the practice assignments designed to complement the learning of fundamentals.
7. A larger elective component, including broadening of the science base beyond Chemistry in second year.

Our proposed new curriculum structure has three strands:
**Core Theory**

As outlined above, our current content coverage is far too extensive – it is worth noting that there are portions of what we cover in our undergraduate chemical engineering science courses that are taught at a graduate level in Europe and North America. It is also worth noting the commitment of ECEENA (Gillett, 2001) that the undergraduate degree should focus on the ‘fundamentals’ with opportunities for advanced study at the graduate level.

From a student learning perspective it is clear that unloading the curriculum will allow us to demand a better grasp of the fundamentals; this is an orientation also in line with international developments (cf. Barton, et al., 2006).

The European agreement on the chemical engineering fundamental core (Gillett, 2001) has been a key resource in defining our core (see Table 2). As we have reduced our core we have checked it against these norms.

<table>
<thead>
<tr>
<th>Table 2. European guidelines for chemical engineering degrees (from Gillett, 2001).</th>
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<tbody>
<tr>
<td><strong>Curriculum element</strong></td>
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<tr>
<td>Basic Science</td>
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<td>Maths</td>
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<tr>
<td>Physics</td>
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<tr>
<td>Chemistry</td>
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<td>Computer usage</td>
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<tr>
<td>Chemical Engineering Core</td>
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<tr>
<td>Thermodynamics/Physical Chemistry</td>
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<tr>
<td>Fluid Mechanics/Transport Phenomena</td>
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<tr>
<td>Unit Operations</td>
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<tr>
<td>Chemical Reaction Engineering</td>
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<tr>
<td>Plant Design (including SHE, Economics, Legislation, etc.)</td>
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<tr>
<td>Equipment/Materials</td>
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<tr>
<td>Process Dynamics and Control</td>
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<tr>
<td>Chemical Engineering Laboratory</td>
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<tr>
<td>Safety, Health &amp; Environment</td>
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<tr>
<td>Electives</td>
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<tr>
<td>In-depth studies of special subjects (for example, Biotechnology)</td>
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<tr>
<td>More thorough application of mathematics to engineering</td>
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<tr>
<td>More thorough application of scientific principles to engineering</td>
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**Core Practice**

In current international curriculum developments in engineering there is a strong focus on project work, ranging from this as a strand of the curriculum as proposed here, through to a full problem-based curriculum where all content is taught through independent student engagement with projects. This is in accord with the positions taken at UQ and Imperial College.
A major emphasis throughout the project work will be on design and analysis, as useful foci for understanding the discipline and the profession (CSEPP, 2007). This is where systems thinking will be developed. We will also focus not only on large-scale processes, but also on small-scale processes.

The practice strand will also involve practical activities including laboratory investigations. Much of our current emphasis in practical work is obtaining and analysing data, which is aimed more at the use of data in research than plant operations. The use of practical demonstrations to build understanding of fundamentals will be an important aspect of the ‘fundamental’ core.

This strand will include industrial exposure, both through real problems tackled in class and through field trips and vacation work.

The key ‘ancillaries’ to chemical engineering science that are needed for conducting design, including heuristics, risk and safety, social and environmental impacts, financial assessments, will all be addressed in this strand, on some occasions through direct instruction, but also more frequently in terms of information that students need to locate and use (a form of PBL).

In terms of outcomes, this strand is also a space where students will need to demonstrate that they can ‘work on their own’. A complex balance will need to be struck between support and independence.

**Electives**

The increased elective component of the curriculum, in line with international developments, serves a number of purposes. Firstly, it is recognised that students need to get exposure to knowledge areas outside engineering, for example in the humanities, and in these areas it is the broad outcomes that are important and not necessarily the particular subject. Secondly, it is clear that student ownership of some of their curricular choices will increase motivation and interest. Thirdly, although the undergraduate degree focuses on fundamentals with specialisation mostly at a postgraduate level, it is useful to give students some opportunity to craft a degree that reflects their particular interests and strengths.

The elective strand will therefore have different components with specified outcomes. These will include the following:

a. Basic Science Elective

The current curriculum, reflecting the petrochemical origins of the chemical engineering discipline, includes relatively advanced study in Chemistry (till second year). With graduates heading for careers in areas such as minerals processing or bioprocessing, we will have electives in Geology and Microbiology as well as Chemistry.

b. Advanced Chemical Engineering Science.

These electives reflect the research specialities of academics. It might be noted that these courses, with small class sizes, would offer opportunity for different forms of teaching and assessment.

c. Humanities electives

The current curriculum specifies one semester course in liberal arts. In the new curriculum we will increase this specification by requiring one additional language, and one course in an area entitled ‘Thinking about the Social World’, in line with curricula especially in North America.
d. Chemical Engineering Research Project

The final year research project will be located in this strand, since it involves advanced study in a particular area. Students essentially ‘elect’ to follow a project in a chosen area, with commonly specified outcomes.

**Assessment and progression**

Key features of our curriculum which respond to these issues are the following:

**Year based assessment decisions**

The current curriculum, with multiple courses in every semester, involves a large number of unrelated assessments for the student. These are largely marks on exam papers, and a student who gets 52% probably does not know much more than the student who gets 48%. This contrasts to the assessment modes we have been using in our fourth year project courses, where a number of marks are gathered for parts of the course but an overall pass/fail decision is made as a professional judgement, not a numerical calculation, and borderline students are carefully assessed in a range of modes to be sure that the right decision has been taken.

This new curriculum will involve fewer overall assessment decisions although many small assessments including examinations will contribute to these decisions. We are proposing, for example, having one large chemical engineering core course in every year of study, encompassing both Theory and Practice. Throughout this course students will write tests and examinations and do projects, but the final pass/fail decision will be taken by a panel of assessors. Importantly, there will be particular requirements on parts of the course, i.e. a student will not be able to simply pass ‘on average’ but will need to demonstrate understanding in all key topics.

**Using extra time in the year for ‘catch up’**

Students whose in-course assessments have demonstrated that they are not at the required level by the middle of the year will be required to work on areas of weakness during part of the mid-year vacation. Those who do not meet the criteria for passing at the end of the course will use part of the vacation time for further work on mastering the material followed by supplementary assessment, along the lines of what we are currently doing in our second year summer term course. With smaller groups and intensive instruction, this will be a good opportunity for students to be able to develop the necessary grasp of the material. Those who will be promoted to the following year, those who still do not will be required to repeat the full year.

This aspect of the curriculum design responds logically to the observation that at UCT we currently use only 60% of the available year for teaching and examinations (31 weeks out of 52). At most we would increase this to 75% (39 weeks out of 52), leaving the students a quarter of the year to relax and spend time with their families. The impact of this change would be even smaller for weaker students in the first year, many of whom would have been returning to write supplementary examinations, both in July and January (and having to pay extra for them, as well as frequently failing them anyway). Our plan is that there will be no extra fees for these catch-up opportunities, and that we would raise resources to help students pay for the extra university residence costs, should this be a problem for them. Many of our students do not have the opportunity to work or travel during the vacation and thus it is often wasted time for them. This arrangement will allow for better use of the year for students.
Mastery assessment

As noted above, along with a reduced core of fundamentals we need assessment that rigorously assesses student understanding of the fundamentals. We are attracted by the ‘mastery tests’ adopted by both Imperial College and the University of Sydney. Some of the testing in the Core Theory strand will be in this mode. These will be entirely straightforward questions similar to those tackled in class, with no time pressure, but students will be required to obtain a very high level of correctness, of the order of 80%. The mastery tests that are scheduled during the semester will have repeat options for students to reach the required level. We envisage that during the final examination period there will be an oral examination over all topics from the year, which students will have to pass at a required level.

We note that it will not be easy for academics who have been used to a conventional mode of testing, to set an appropriate mastery test. We will need extensive collegial interactions especially in the early years of rollout to get this right. The year teams will be a key resource in this regard, with the year coordinator playing a key role.

Implications

Integration of material both within a year and across years is a major challenge. Although the major means of developing fundamental understanding will be through direct instruction and small group problem solving, it is clear that application of these fundamentals in the project context should help build this understanding. Thus the new curriculum will crucially need to promote horizontal integration, with the teaching of fundamentals in time for these aspects to appear in project work.

A number of mechanisms will need to be in place to ensure that this takes place. Firstly, the overall planning of course content will need to arrange pacing and sequencing to meet this goal. This is important both in the planning process as well as during the actual curriculum rollout, especially in the first year a particular course is run.

In terms of vertical integration through the years, one key factor is the teaching of project-oriented work with a design focus from first year throughout. It has been argued that the lack of this feature in our current curriculum is the most serious factor influencing students’ ability to integrate their knowledge and apply it in final year (Kotta, 2008). Progression through this strand will be crucial to ensure that students develop a coherent and steadily enlarging approach over the years.

Two strands in the curriculum will be taught by academic staff in the Department of Chemical Engineering: the Core Theory strand and the Core Practice strand. The teaching of the Core Theory will require skill at developing strong conceptual understanding with a related ability to test the fundamentals in mastery tests. The teaching in this strand will also differ from our current offerings in that we will aim for less lecturing with more active student work on problems. The Core Practice strand will require a different set of teaching skills. The design of projects will be particularly demanding upfront. The ‘teaching’ of this strand will require an ability to manage and promote group work, and to provide timely and regular feedback to students. The assessment in this strand is also possibly more challenging than what we are used to more conventional courses.

The advanced Elective courses in research specialisations in chemical engineering will be an opportunity for staff to teach their research interests to small groups of students who have elected to pursue this area in more depth.
We need to think smartly about how we best use our postgraduate students in our teaching teams. They might be especially crucial providing regular quality feedback in the Core Practice work. It is intended that we will employ senior postgraduates in our vacation time ‘catch up’ courses as we have done so far.

A detailed analysis of the staff workload this new curriculum will generate indicates that it will require more effort that the current curriculum, although we are agreed that our current way of measuring this under-rates the workload. We also note that relative to similar departments in the developed world, we are severely understaffed, producing 5-6 graduates per staff member, compared to 3-4, or even less.

With respect to physical resources we are fortunate that a new engineering building is currently under construction that will provide us with a home room for each study year. We are also intending that each student will have his/her own laptop so that we can easily switch between giving students input to them working actively on problems in the homeroom.

Conclusions

The proposed new curriculum has been built on the foundation of both an understanding of the educational issues surrounding our programme, and experience applying new teaching and learning paradigms in the classroom. Successful implementation will require considerable engagement with the departments offering service courses, as well as careful integration between the theory and practice components within and between years.

We believe that the new curriculum that we have developed (with its associated teaching and learning processes and assessment strategies) will be more responsive to student aspirations as well as the needs of the workplace, and will therefore produce graduates who are better able to rise to the challenges of the world on the future. Our experience with implementing many of it features will hopefully stand us in good stead to rise to the challenge of delivering this curriculum. We trust that others will benefit from what we have shared here.

References


Analysis of Trends in National Diploma Student Success Rates in Mechanical Engineering at the Durban University of Technology

Bruce Graham¹ and Mark Walker²

Department of Mechanical Engineering, Durban University of Technology, South Africa
¹bruceg@dut.ac.za, ²walker@dut.ac.za

Abstract

The Department of Mechanical Engineering at the Durban University of Technology wished to establish how changes made to the National Diploma in Mechanical Engineering, had affected success rates, as well as evaluate the effectiveness of the diploma’s Work Integrated Learning (WIL) component. Success rates were calculated for a period of eight semesters, starting with the first semester 2007, in order to determine these effects. The Average time taken to complete WIL, the portion of the academic component undertaken before starting WIL and the percentage of students dropping out during WIL, for this period, was also established. The introduction of the new National Senior Certificate and the reduction of contact time were found to have little or no effect on success rates. The moving of Electrotechnology I from the first semester to the third semester and the introduction of supplementary exams both saw improvements in success rates. The elimination of electives saw a decrease in the success rates of certain fourth semester subjects. It was found that WIL was not meeting the intended academic outcomes, the average student does not complete WIL within the minimum time frame, and that a significant portion dropout during or after registering for WIL.

Introduction

Engineering education in South Africa faces many challenges. There is a scarcity of students that both qualify for, and choose to enter engineering programs and many of those that do have poor educational backgrounds and subsequently underperform in the higher education environment (Case, 2006). Throughput rates for undergraduate engineering courses in South Africa are far from optimal, with students studying towards the National Diploma at Universities of Technology faring the worst (Roodt & du Toit, 2009). Scott et al. (2007) state that the existing higher education system is no longer effective as the majority of students entering the sector does not complete their studies. They continue by stating that increasing the intake of students into engineering programs will not be an efficient means of increasing graduation, but rather that the success within these programs should be targeted.

The number of science, engineering and technology graduates entering the job market is not sufficient to meet the demand for these scarce skills (Cosser, 2010 & Taylor, 2008). Further, the shortage of engineering skills is an impediment to economic growth and the government’s aims of the Accelerated and Shared Growth Initiative South Africa. (Roodt & du Toit, 2009).

For the reasons outlined above, departments should be investigating and implementing methods to increase student success within their programs. Fraser (2008) suggests the appointment of faculty educational specialists, maintaining the quality of incoming students, improving the faculty learning climate, developing staff teaching skills and ensuring effective student support. The curriculum can also be renewed to effectively integrate literacy and numeracy (Owen & Schwenger, 2008) and increase the level of engineering application in
entry level courses (Klingbeil, Mercer et al, 2004) in order to improve student success. A number of changes, some with the specific intention of increasing student success, to the National Diploma in Mechanical Engineering, have been made over the last five years. Before embarking on a curriculum renewal process the Department wished to gain a clearer picture of success rates in the program as well as determine the effect of changes made. The changes to the program were: the introduction of supplementary examinations, the removal of various elective offerings, the change of semester in which Electrotechnology I was offered and the reduction in contact time per subject. The department also admitted students with the new NSC qualification (which replaced the old Matric Senior Certificate) for the first time in 2009.

The department also believed that the manner in which Work Integrated Learning (WIL) was offered had a negative effect on student throughput, and did not provide a substantial opportunity to integrate experience gained in industry with the classroom experience.

**Program Structure**

The department of Mechanical Engineering at the Durban University of Technology currently offers a National Diploma. There are two options within the diploma: a mainstream option and a mechatronics option. The diploma consists of four semesters of academic tuition and two semesters of work integrated learning. The four academic semesters are known as S1, S2, S3 and S4 respectively, whilst the two periods of work integrated learning are known as P1 and P2 respectively. Students who have completed the National Diploma may opt to pursue a Bachelors Degree in Technology, which is offered on a full or part-time basis.

**Theoretical Framework**

This paper will examine the success rates of students, across four semesters of study, over a period of four years, starting with the first semester of 2007 and ending with the second semester of 2010 and attempt to show the effects, either positive or negative, that these interventions have had on the success rates. As a number of these changes took place at the same time conclusions will be stated in terms of probability rather than certainty. The paper will also determine the average time that it takes students to complete WIL as well at what stage of the academic program they first embark on it. The research was undertaken from the perspective of the department to determine the where it stood in terms of success rates and what the effects of any changes had been.

The paradigm used was Positivist, as the aim was to identify factors that influence outcomes as opposed to factors affecting individual learners, where a Constructivist paradigm may have been more suitable (Jawitz & Case 2009). The study was nonexperimental and quantitative in nature, and all data was retrieved from the University ITS.

**Success Rates**

The pass rate is the percentage of students passing a subject divided by the number writing the examination. Success rate is the percentage of students that achieved a passing grade (including supplementary examinations) divided by the total number of students registered for the subject. Instances may occur where a subject may have a good pass rate but a poor success rate. This occurs if large numbers of students do not achieve the required coursemark subminimum and are denied entrance to the examination. For this reason success rates will be used here as the measure of student success. Success rates were determined for each subject, in each semester for the period mentioned. Students registered on a non-diploma basis were excluded from the calculation. Average success rates for each level of the program were
found by dividing the total passes in all subjects at each level by the total registrations at that level, capturing the entire population. Data collected is nominal with success measured in terms of pass or fail. The data collected is considered reliable and valid as it measures the success of every student for every subject that they were registered for.

**Electrotechnology I**

Because Electrotechnology I (serviced by the Department of Electrical Engineering) success rates were far below that of other subjects at the same level, it was decided, as of first semester 2009, to move the mainstream subject offering from the first semester (S1) to the third semester (S3) level of study. As the subject was serviced there were few interventions that the department could implement in order to increase success rates. The department felt that if the subject was offered later in the diploma then students may be more mature and possess better learning and/or study skills and so perform better.

The success rates for this subject are shown in Figure 1 for the periods mentioned. With the same lecturer taking this course over the whole period, and little or no change to the syllabus, it can be surmised that the move of this course to S3 in 2009 was one of the factors behind the dramatic increase in success rate.

![Figure 1. Electrotechnology I success rates.](image)

This move would have caused the mainstream classes of 2009 to be smaller than usual (Table 1) as they would comprise almost exclusively of repeat students. From the beginning of 2010 the mainstream course would once again include large numbers of first time students and the success rate remains at around 80%. Weaker students may have dropped out, or have been excluded, from the program before reaching S3, contributing to lower class sizes and playing a role in the increased success.

**Table 1. Electrotechnology 1 class size.**

<table>
<thead>
<tr>
<th>Semester</th>
<th>'07 sem 1</th>
<th>'07 sem 2</th>
<th>'08 sem 1</th>
<th>'08 sem 2</th>
<th>'09 sem 1</th>
<th>'09 sem 2</th>
<th>'10 sem 1</th>
<th>'10 sem 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mainstream</td>
<td>113</td>
<td>76</td>
<td>131</td>
<td>88</td>
<td>38</td>
<td>44</td>
<td>60</td>
<td>63</td>
</tr>
<tr>
<td>Mechatronics</td>
<td>-</td>
<td>-</td>
<td>20</td>
<td>14</td>
<td>24</td>
<td>14</td>
<td>29</td>
<td>11</td>
</tr>
</tbody>
</table>

Students registered for the Mechatronics option within the diploma would not be able to take this subject in their third semester as it is a prerequisite for multiple S2 and S3 mechatronics subjects. The timetable is arranged so that the mainstream and mechatronics students attend
the same classes together, allowing for direct comparison between these two groups (as can be seen in the Figure 1).

The mechatronics option, first offered by the department in the first semester of 2008, has only one intake of students per year, as opposed to the mainstream’s dual intake. The intake for this course is always twenty students or less and this should be borne in mind when looking at the data. The single intake explains the marked difference in success rates between the first and second semesters of the mechatronics cohort, as the second semester cohort would comprise entirely of repeat students. The mainstream students would always be a mix of first time and repeating students.

The disparity between the success rates for mainstream and mechatronics students in the first semester of each year, again gives credence to the position that first semester students do not possess the prerequisite academic skills to succeed in this course, as it is currently offered, at the S1 level.

At the time when this subject was moved there was some debate as to whether this intervention would negatively affect the success rates of other S3 subjects as no subject was moved down in the curriculum, thereby increasing the S3 workload. It was however believed that a small reduction in the success rates at S3 would be justified if matched by a dramatic increase in the success rate for Electrotechnology I.

![Figure 2. Average S3 success rates.](image)

Table 2. Overall S1 success rates

<table>
<thead>
<tr>
<th>Semester</th>
<th>'07 sem 1</th>
<th>'07 sem 2</th>
<th>'08 sem 1</th>
<th>'08 sem 2</th>
<th>'09 sem 1</th>
<th>'09 sem 2</th>
<th>'10 sem 1</th>
<th>'10 sem 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>497</td>
<td>442</td>
<td>454</td>
<td>305</td>
<td>306</td>
<td>356</td>
<td>430</td>
<td>420</td>
</tr>
<tr>
<td>Passes</td>
<td>383</td>
<td>270</td>
<td>318</td>
<td>244</td>
<td>254</td>
<td>263</td>
<td>348</td>
<td>353</td>
</tr>
<tr>
<td>Success rate</td>
<td>77%</td>
<td>61%</td>
<td>70%</td>
<td>80%</td>
<td>83%</td>
<td>74%</td>
<td>81%</td>
<td>84%</td>
</tr>
</tbody>
</table>

Strength of Materials III (SM3), showed a fairly dramatic increase during over the five semesters, starting 2007, and Mechanical Engineering Design III (MD3) had two semesters where results were far below the norm for this subject. The increase in the success rates of SM3 is thought to be due to both the introduction of tutors and the subsequent decline in class size, caused in part by the increased success. The poor results for MD3 coincide with the lecturer taking study leave and a part-time lecturer replacing him.
Figure 2 shows that average success rate for S3 students has remained fairly stable over the period if these two subjects are ignored. This implies that the additional workload added by introduction of Electrotechnology I to the S3 curriculum, in the first semester 2009, has had no significant effect of the success of other subjects. This cannot be exclusively determined due to the changes that have occurred in the other subjects.

The New NSC

There was concern that the level of mathematics and physics at grade 12, offered in the new NSC, would prove to be inadequate for the technical courses of the mechanical engineering program. A compulsory geometry module was added to the program in S1 to help address the lack of geometry in the NSC qualification. The department equated the NSC grade level 4 with the senior certificate Higher Grade E and the Standard Grade C, and used these as the minimum Mathematics and Science entrance requirements.

In order to test that these levels were similar, the success rates for both S1 and S2 were compared prior to and post the introduction of students with NSC qualifications. The majority of new students entering S1 in the first semester 2009 would hold the NSC qualification, however repeating students would hold the old senior certificate. Students that do not complete S1 within two semesters are excluded from the program, so by the second semester 2009 NSC students would comprise the majority of the S1 class. The first NSC students would enter S2 in the second semester 2009 and comprise the majority by the beginning of 2010.

![Figure 3. Average S1 success rates.](image)

Table 3. Overall S1 success rates

<table>
<thead>
<tr>
<th>Semester</th>
<th>'07 sem 1</th>
<th>'07 sem 2</th>
<th>'08 sem 1</th>
<th>'08 sem 2</th>
<th>'09 sem 1</th>
<th>'09 sem 2</th>
<th>'10 sem 1</th>
<th>'10 sem 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>723</td>
<td>384</td>
<td>824</td>
<td>414</td>
<td>716</td>
<td>488</td>
<td>781</td>
<td>495</td>
</tr>
<tr>
<td>Passes</td>
<td>536</td>
<td>245</td>
<td>547</td>
<td>240</td>
<td>546</td>
<td>382</td>
<td>633</td>
<td>361</td>
</tr>
<tr>
<td>Success rate</td>
<td>74%</td>
<td>64%</td>
<td>66%</td>
<td>58%</td>
<td>76%</td>
<td>78%</td>
<td>81%</td>
<td>73%</td>
</tr>
</tbody>
</table>

The average success rates for S1 students (see Figure 3) shows an increase as of the first semester of 2009. This coincides with both the first intake of NSC students and the removal
60

of Electrotechnology I from the S1 curriculum. If the results for Electrotechnology I (ET1) are removed from the calculation there is very little variation between the rates for the whole period. This implies that the NSC has had little or no effect on the overall success rate of S1 students. Nonetheless, it should also be borne in mind that the overall workload of the S1 students was decreased by the removal of Electrotechnology I, and that contact time was reduced at this time as well. The investigation into the reduction in contact time, later in this paper, shows that the reduction thereof had no measurable effect. It is possible that the NSC students may be slightly weaker than the Senior Certificate students, and this is being masked by their decreased workload.

All S1 subjects, with the exception of Mathematics I, have maintained a fairly consistent success rate over the period in question, again implying that the impact of the NSC has been negligible on individual subjects. Mathematics I is taught by a different lecturer each semester which may explain the variation of results for this subject.

Table 4. Overall S2 success rates

<table>
<thead>
<tr>
<th>Semester</th>
<th>'07 sem 1</th>
<th>'07 sem 2</th>
<th>'08 sem 1</th>
<th>'08 sem 2</th>
<th>'09 sem 1</th>
<th>'09 sem 2</th>
<th>'10 sem 1</th>
<th>'10 sem 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>472</td>
<td>572</td>
<td>449</td>
<td>649</td>
<td>522</td>
<td>782</td>
<td>806</td>
<td>916</td>
</tr>
<tr>
<td>Passes</td>
<td>298</td>
<td>380</td>
<td>275</td>
<td>338</td>
<td>284</td>
<td>355</td>
<td>427</td>
<td>523</td>
</tr>
<tr>
<td>Success rate</td>
<td>63%</td>
<td>66%</td>
<td>61%</td>
<td>52%</td>
<td>54%</td>
<td>45%</td>
<td>53%</td>
<td>57%</td>
</tr>
</tbody>
</table>

The average S2 success rates (Figure 4) show a decline at the second semester 2007. They also show a very poor result for the second semester of 2009, in part due to a success rate of 23% for Engineering Materials and Science I. This particular result was a once-off phenomenon attributable to a new lecturer taking over the course. If this result is removed from the calculation the success rate for this particular semester increases to 50%.

The first NSC students would have started S2 classes in the second semester of 2009 with them constituting the bulk of the class by the first semester 2010. The fact that the dip starts before this time, and then stabilises in the first semester 2008 onwards, indicates the introduction of the NSC had very little or no effect on the S2 success rates.

Figure 4. Average S2 success rates.
As little or no change in success can be attributed to the NSC, it can be concluded that the entrance requirements were appropriately aligned, as long as students took the co-requisite geometry module.

**Reduction in Contact Time**

The reduction of contact time, as a consequence of the decision to move from a 45 minute to a one hour period at the beginning of the first semester of 2009, was also investigated. The change to one hour periods saw an approximate 20 percent reduction in contact time per subject. There was much debate at the time as to whether the department was ‘over-teaching’ or not, with many lecturers predicting dire consequences if contact time were to be reduced.

Average success rates for the four semesters preceding the introduction and the four semesters afterwards were examined at all S levels. If there was an effect it was supposed that there would be a steep drop coinciding with the reduction in contact time, followed by improvement as the students and staff adjusted to the new regime.

The S1 success rates show an increase coinciding with this change, but as discussed previously, if the results for Electrotechnology I are removed (Figure 3), then success rate remains relatively constant across the whole eight semester period. As the reduction in contact time occurred at the same time as the new NSC students entered the systems and Electrotechnology I was moved from S1 to S3, it is more useful to look at the S2, S3 and S4 results to determine the effect. The S2 (Figure 4) and S3 (Figure 2) success rates shows no decrease at the time of the change, and remain fairly stable indicating that the reduction in contact time had no real effect.

**Table 5. S4 overall success rates.**

<table>
<thead>
<tr>
<th>Semester</th>
<th>'07 sem 1</th>
<th>'07 sem 2</th>
<th>'08 sem 1</th>
<th>'08 sem 2</th>
<th>'09 sem 1</th>
<th>'09 sem 2</th>
<th>'10 sem 1</th>
<th>'10 sem 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sample size</td>
<td>302</td>
<td>405</td>
<td>259</td>
<td>335</td>
<td>282</td>
<td>346</td>
<td>239</td>
<td>422</td>
</tr>
<tr>
<td>Passes</td>
<td>221</td>
<td>233</td>
<td>151</td>
<td>229</td>
<td>206</td>
<td>230</td>
<td>146</td>
<td>229</td>
</tr>
<tr>
<td>Success rate</td>
<td>73%</td>
<td>58%</td>
<td>58%</td>
<td>68%</td>
<td>73%</td>
<td>67%</td>
<td>61%</td>
<td>54%</td>
</tr>
</tbody>
</table>

The S4 success rates (Table 5) show a wide variation across the period in question, yet no change that coincides with the reduction contact time. The first semester 2009 has one of the highest success rates. This occurs immediately after the reduction in contact time when one would have expected a decrease due to students and staff adjusting to the reduced contact time. Thereafter the rate decreases which may be explained in the section in this paper about the removal of electives. No substantial conclusion can be drawn from the S4 data with regard the effect the reduction of contact time has had on success rates.

The effect of the reduction on the S1 and S4 results is difficult to quantify, but as the effect on the S2 and S3 results has been negligible, it can be concluded that the effect on the S1 and S4 course success rates would in all likelihood be negligible too.

**Removal of Electives at S4**

The department found that a large number of the students were entering the BTech program without having all the necessary prerequisite subjects (the entrance requirement is simply a National Diploma in mechanical engineering). This had a negative impact on the throughput rate of the BTech program as many students needed to register for diploma level prerequisite subjects in tandem with BTech subjects (that students had the prerequisites for). This also provided a major obstacle for students wishing to register for the BTech on a part time basis as they could not attend the daytime offering of these prerequisite subjects. It was decided...
that the diploma program should be rearranged such that all students graduating with the diploma would have completed all the necessary prerequisites for the BTech program. This required the removal of certain electives as well as making other subjects compulsory in the diploma program.

Mechanical Manufacturing Engineering II and Electrotechnology II were removed from the S2 curriculum, Mechanical Manufacturing Engineering III from the S3 curriculum and Manufacturing Management III and Electrotechnology III form the S4 curriculum, all effective from the first semester 2009.

By removing these electives, some of which were perceived as ‘soft’ options, and increasing the number of compulsory ‘difficult’ subjects, the department believed that there may be a negative effect on the success rates in these now compulsory subjects. It was felt that any decrease in success rates within the diploma program would be outweighed by positive changes to BTech throughput rates.

The elective course class sizes were generally quite small - on average a third of that of the compulsory subjects, so the impact of removing them was not expected to be of major significance to the average success rates at the lower levels (and so was ignored).

Previously, students could complete the diploma with only two majors at the S4 level. With the electives removed they would now have to complete five major subjects of which Theory of Machines III, Machine Design III, Applied Strength of Materials III and Mathematics III would become compulsory. The rule making these subjects compulsory only applied to students first entering the diploma in 2009, but the removal of the electives would leave fewer options available to current S4 students, such that students would need to complete the majority of these anyway.

![Figure 5. S4 success rates.](image)

Students that found difficulty with a particular stream, Strength of Materials for example, could have avoided the S4 version (called Applied Strengths III) by using credits gained earlier, or at the S4 level, from electives. As this is no longer possible the department expected a decrease in success rates in some of these subjects newly made compulsory. An
analysis of the individual S4 subject success rates will give an idea of what the effect of the removal of electives has been.

Figure 5 shows the two discontinued subjects, Electrotechnology III and Manufacturing Management III, as having success rates significantly higher than the mean, but because of limited class size they have very little influence on the overall success rate. Students entering S4 in the first semester of 2009 may have already been carrying credits from earlier levels and so avoided the need to register for subjects they found problematic. Students entering in the following semesters would increasingly do so without any of the discontinued electives.

Theory of Machines III trends downwards, starting from the first semester 2009, with Applied Strength of Materials III and Machine Design III both trending downwards, starting from the second semester of 2009. It is worth noting that none of these subjects have fallen below their previous low. It will be interesting to see if the Semester 1 2011 results stabilise.

Although the success rate for Machine Design III has decreased since effectively being made compulsory, the number of students passing this subject has doubled which will prove beneficial to the BTech program student numbers in the future.

It would seem that removing electives, effectively making certain subjects compulsory, has resulted in a decrease in success rates for some of those subjects as was expected. The advantage is that any student starting the Diploma after 2009 will graduate with all prerequisite subjects for the BTech program.

**Supplementary Examination**

Prior to the implementation of supplementary examinations in 2006, students obtaining a final mark of between 45 and 49%, and those who have achieved a course mark of above 60% regardless of their examination result, could rewrite the examination during the following examination session, a delay of one full semester. There was no real benefit for the student, other than saving the full subject registration fee the following semester. This also had no benefit to the department’s success or throughput rates.

Supplementary examinations are now written directly after the release of examination results, with results being released before the next registration period. By their nature supplementary examinations must positively affect the success rate of individual subjects, and hence the graduation and throughput rates of the program.

Success rates for all subjects, both prior to and subsequent to the supplementary session, were collated. The difference between these two values shows the percentage point increase in success rates attributable to the supplementary examination in each subject. Continually assessed courses would have a percentage point increase of zero points (because there are no exams/supps for continually assessed courses).

**Table 6. Percentage point increase due to supplementary exam.**

<table>
<thead>
<tr>
<th></th>
<th>'07 sem 1</th>
<th>'07 sem 2</th>
<th>'08 sem 1</th>
<th>'08 sem 2</th>
<th>'09 sem 1</th>
<th>'09 sem 2</th>
<th>'10 sem 1</th>
<th>'10 sem 2</th>
<th>mean</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>S1</strong></td>
<td>2.6%</td>
<td>1.1%</td>
<td>1.3%</td>
<td>1.4%</td>
<td>0.2%</td>
<td>0.2%</td>
<td>0.7%</td>
<td>0.2%</td>
<td>1.0%</td>
</tr>
<tr>
<td><strong>S2</strong></td>
<td>3.2%</td>
<td>3.8%</td>
<td>3.3%</td>
<td>4.6%</td>
<td>6.8%</td>
<td>2.5%</td>
<td>1.0%</td>
<td>1.4%</td>
<td>3.3%</td>
</tr>
<tr>
<td><strong>S3</strong></td>
<td>5.3%</td>
<td>2.0%</td>
<td>5.4%</td>
<td>3.7%</td>
<td>5.8%</td>
<td>5.7%</td>
<td>4.1%</td>
<td>10.6%</td>
<td>5.3%</td>
</tr>
<tr>
<td><strong>S4</strong></td>
<td>6.3%</td>
<td>4.7%</td>
<td>3.5%</td>
<td>7.6%</td>
<td>10.4%</td>
<td>7.1%</td>
<td>7.1%</td>
<td>3.7%</td>
<td>6.3%</td>
</tr>
</tbody>
</table>
These rates were then weighted according to the number of students registered and combined, including continually assessed courses, to determine the magnitude of the effect on each level. The mean values shown in Table 6 are simple arithmetic means, and do not include any class size weighting.

The majority of the courses in the S1 curriculum are continually assessed and hence the percentage point increase can be ascribed to the only examinable subject, Mechanics I. The S2, S3 and S4 levels each contain one subject that is continually assessed.

Although the supplementary examinations only appear to have a small impact on the overall success of the program their effect is perhaps more valuable when students encounter difficulty with an individual examination. Out of 136 supplementary exams written over the period, 24 contributed over 10 percentage points to the subject’s success rate. 4 of those 24 contributed over 20 percentage points to a subject’s success rate. This indicates that although the supplementary exams do not contribute greatly to the department’s success rate, at certain times they allow a significant number of students the opportunity to improve their results in an individual subject. For this reason it is the author’s opinion that every student that fails an exam should be granted a supplementary examination.

Work Integrated Learning

Work Integrated Learning (WIL) is described by the South Africa Society for Cooperative Education (Forbes, 2007) as a structured part of a qualification that integrates work experience with classroom study. WIL cannot be viewed as an add-on to the curriculum (Groenewald T, 2001), but rather should be integrated with teaching and learning within the classroom.

As mentioned, the diploma includes two formal Work Integrated Learning periods, each six months in duration, called P1 and P2 respectively. It was originally intended that WIL would be ‘sandwiched’ between the academic semesters to ensure maximum integration between the academic and experiential components. Due to the perceived difficulty in students finding placements the department has for many years allowed students to undertake the WIL components at any time within their course of studies. It has been suspected that this practice has led to the majority of students registering for WIL upon completion of the academic portion of the program and therefore reducing the effectiveness of WIL by relegating it to an add-on.

To determine if this is so, the academic records of all students graduating in the five previous graduations sessions were generated. The number of subjects each student completed prior to P1, between P1 and P2, during P1, during P2, and subsequent to P2, were collated.

Anecdotal evidence also suggested that a large portion of students spent significantly more time than necessary to complete WIL, which impacted on throughput rates. This was assumed to be due to difficulty in finding placements, as well as late WIL registration and log book submission.

To determine the average time to complete WIL, the number of semesters each student spent registered for, or attempting to find placement for WIL was measured. Students who registered for WIL and completed it more than a semester later, without returning to the academic program, were assumed to have remained in the workplace, and this time was included in the calculation.
Table 7 shows that the percentage of students completing all academic components of the program before starting P1 as well as the percentage of students who have completed all academic components of the program by the end of P1.

**Table 7.** Students completing all academic components before or during P1.

<table>
<thead>
<tr>
<th>Academic Component</th>
<th>Apr-09</th>
<th>Sep-09</th>
<th>Apr-10</th>
<th>Sep-10</th>
<th>Apr-11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completed before P1</td>
<td>51%</td>
<td>63%</td>
<td>53%</td>
<td>63%</td>
<td>57%</td>
</tr>
<tr>
<td>Completed by end P1</td>
<td>65%</td>
<td>63%</td>
<td>62%</td>
<td>70%</td>
<td>63%</td>
</tr>
</tbody>
</table>

Students completing subjects during WIL include those taking advantage of the University’s last outstanding subject rule who are granted a special examination in the next available examination session. It also includes students who failed their last subject outright and register for this subject concurrently with P1. They typically do not attend classes and only return to the University to write the tests and examinations for these subjects. This contravenes the departmental rules, but the current registration system cannot identify these students and prevent them from doing this.

It can be seen in Table 7 that approximately two thirds of students have completed all academic components, or have just one subject to attempt/repeat, before starting their WIL. The objective of WIL to integrate work experience with academic learning is clearly not being achieved in these cases.

**Table 8.** Average subjects completed by students during or after P1.

<table>
<thead>
<tr>
<th></th>
<th>Apr-09</th>
<th>Sep-09</th>
<th>Apr-10</th>
<th>Sep-10</th>
<th>Apr-11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>2.4</td>
<td>2.8</td>
<td>3.3</td>
<td>3.0</td>
<td>3.8</td>
</tr>
<tr>
<td>Std Dev</td>
<td>2.5</td>
<td>1.4</td>
<td>4.2</td>
<td>2.2</td>
<td>4.1</td>
</tr>
<tr>
<td>Median</td>
<td>2.0</td>
<td>3.0</td>
<td>2.0</td>
<td>2.5</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Of the students who engage with the academic program after registration for P1, they generally register for very few subjects, having already completed the majority beforehand. Table 4 shows that of these students the average (median) only completes about two subjects after their first WIL registration. The mean is generally higher than the median as each cohort tends to include a very limited number of students who complete a significant portion of their academic components after either P1 or P2.

In order to graduate students require a minimum of twenty four subjects. It is therefore apparent that even the minority of students who engage with the academic program after WIL do so in a very limited manner.

**Table 9.** Number of semesters taken to complete P1 and P2.

<table>
<thead>
<tr>
<th></th>
<th>Apr-09</th>
<th>Sep-09</th>
<th>Apr-10</th>
<th>Sep-10</th>
<th>Apr-11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>3.2</td>
<td>3.5</td>
<td>3.1</td>
<td>3.6</td>
<td>3.6</td>
</tr>
<tr>
<td>Median</td>
<td>3</td>
<td>3</td>
<td>2</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Min time</td>
<td>42%</td>
<td>28%</td>
<td>51%</td>
<td>37%</td>
<td>49%</td>
</tr>
</tbody>
</table>
Table 9 shows the average number of semesters a student takes to complete the full WIL portion of the program. The mean value is useful with relation to the effect that WIL has on the programs throughput rates, whilst the performance of the ‘average’ student is better described by the median and by the percentage finishing in the minimum time.

It is worth noting that the marginal increase in the mean for the September 2010 and April 2011 graduations are caused by the inclusion of students that have taken over ten semesters to complete WIL. If these few exceptions are ignored, the mean for these two semesters become 3.3 and 3.0 respectively.

**WIL dropouts**

It is believed that after securing WIL placement and hence gainful employment a number of students choose to stay in industry and never return to the University to complete their studies. In order to establish this, the registrations and passes for both P1 and P2 were recorded from the first semester 2007 until the second semester 2010.

It was discovered that the first semester of each year always has a larger number of first time students registered for P1 than the second semester. This indicates that students are most likely to start WIL in the first semester of each year. Conversely, the number of first time registering P2 students in the second semester is always equal to or larger than the number in the first semester. The average success rates for P1 and P2 were found to be 52 and 63% respectively.

Due to the significant variation in first time registrations per semester, and the large number of repeating students, it is difficult to obtain the percentage of students that drop out over any particular semester. It is much more instructive to take the total first time registrations and total passes over the entire seven semester period to calculate the average dropout rate.

<table>
<thead>
<tr>
<th>Semester</th>
<th>1st Time Registrations</th>
<th>Total Passes</th>
<th>Dropout</th>
</tr>
</thead>
<tbody>
<tr>
<td>P1</td>
<td>391</td>
<td>364</td>
<td>7%</td>
</tr>
<tr>
<td>P2</td>
<td>341</td>
<td>313</td>
<td>8%</td>
</tr>
<tr>
<td>P1 &amp; P2 combined</td>
<td>391</td>
<td>313</td>
<td>20%</td>
</tr>
</tbody>
</table>

With regards to Table 10, it can be seen that, from the first WIL registration until the completion thereof, there is a dropout rate of twenty percent. It is feasible that some students return to the university between P1 and P2 and are then excluded academically, due to poor performance, but as seen previously the majority of students have either completed all, or the majority of the academic program before embarking on WIL. It is therefore unlikely that academic exclusions play any significant part in this dropout rate. As these students, by nature of having already completed the majority of the program are capable of graduating, their dropping out is of great concern.

Lecturers that teach both BTech and diploma level subjects suggest that there is a marked improvement in the maturity, commitment and general attitude of the BTech students as compared to the diploma students. They also have suggested that these students tend to grasp the material covered in courses more easily as they may have already had ‘hands on’ experience with the technologies/concepts covered in class. Although this is anecdotal it would still suggest that WIL is still partially meeting its intended outcomes. It may be adding
little value to academic portion of the diploma program but it would appear that some of the intended outcomes such increased maturity, development of communication skills and an increase in learning retention, are being met. Further research would be useful to determine whether these intended outcomes of WIL are indeed being met.

As the supposed benefits of WIL are not having a significant effect on the academic portion of the diploma, it could be argued that it would be more efficient if the current offering of WIL was removed from the program. The perceived benefits mentioned above could be achieved by simply adding an entrance requirement to the BTech program of at least one year post diploma work experience.

A more reasonable solution would be to revise the manner in which WIL is offered to ensure that it is offered in an effective and beneficial manner in the programs developed under the new HEQF.

**Conclusion**

The intervention staged by moving Electrotechnology I to S3 was very successful and the improvement in success rates for the mainstream students exceeded all expectations. The Mechatronics results allow direct comparison and further affirm that the improvement correlates with the move to the higher level. These two separate cohorts, taught in the same classroom at the same time, should lead to some interesting research establishing the causal factors behind this.

The entrance requirements for NSC students was set at the appropriate level, because together with the addition of the co-requisite geometry module, there was very little change in success rates at the S1 and S2 level before and after the introduction of the NSC.

The reduction in contact time in the program has had no measurable effect on the S2 and S3 levels and is assumed to have had no effect on the S1 and S4 levels. From this one can conclude that the department was overteaching prior to this change.

The removal of electives has negatively affected the success rates at the S4 level. This was expected and only the future research will tell if there is a corresponding increase in BTech throughput.

Supplementary examinations have played a small, but in certain instances, valuable contribution to success rates, and this practice should be extended to all students who fail after writing the final examination.

WIL in its current form is not meeting its intended outcomes. It also sees a significant number of academically capable students drop out, and those that do graduate take longer than necessary to complete WIL thereby negatively affecting the department’s throughput rates. The manner in which WIL is offered in the new HEQF qualification must be changed substantially taking all these factors into account.

**References**


Results of the First Year of the Engineering Augmented Degree Programme at the University of Pretoria

Diane Grayson
Faculty of Engineering, Built Environment and Information Technology, University of Pretoria, South Africa
Diane.Grayson@up.ac.za

Abstract
Beginning in 1994 the University of Pretoria offered a 5-year BEng programme in which the first two years were spread out over three years. However, only about one third of black students graduated after seven years. In 2010 the Engineering Augmented Degree programme (ENGAGE), a new five-year programme, was launched. Five principles guided the design of ENGAGE: (i) students should be supported in making the transition from high school to university; (ii) student workload (time students spend working) should be high throughout; (iii) the volume of work (amount of content covered) should be low initially and increase over time; (iv) support should be high initially and decrease over time; (v) students should encounter familiar subjects early in the program, less familiar subjects later on. ENGAGE comprises a reduced load of mainstream modules accompanied by developmental modules. Developmental modules address students’ need for a range of academic, life and cognitive skills, conceptual understanding and background knowledge. They also help students develop behaviours needed for success, such as attending class and submitting weekly assignments. In 2010, of the 305 students that registered for ENGAGE, 58% passed at least 70% of their modules and could proceed, 53% of white students and 71% of black students. In the old 5-year programme, for the 2009 cohort 46% could proceed, 38% of white students and 50% of black students. This suggests that ENGAGE could become a useful tool for redress in increasing the pool of black engineers. The relatively poor performance of the white students could be due to a combination of attitude and aptitude. Further improvement in student success requires reliable tools for selecting and placing students in programmes according to their ability and level of preparation. Hopefully the National Benchmark Tests will help with this important task.

Introduction and Background
According to the Royal Academy of Engineering (June 2007),

No factor is more critical in underpinning the continuing health and vitality of any national economy than a strong supply of graduate engineers equipped with the understanding, attitudes and abilities necessary to apply their skills in business and other environments.

If this is true in developed countries, how much more important is it in a country like South Africa that has an enormous backlog in the infrastructure needed for a decent standard of living, including clean water supply, sanitation, housing, food, transportation and electricity? South Africa has far too few engineers to meet these needs for the whole population. According to Lawless (2005), the ratio of registered engineer to population is 1:3166 in South Africa, compared with 1:543 in Malaysia, 1:389 in the USA and 1:130 in China. Nor is this situation likely to improve any time soon if we continue to run our engineering programmes in the future as we have in the past. According to the Council on Higher Education (October 2009), the graduation rate for Science, Engineering and Technology in 2007 was 17.0%. Although this is an increase over the 2004 figure of 15.0%, in terms of the number of
graduates with engineering qualifications, there was a change from 6 032 in 2004 to 8 381 in 2007, a miniscule fraction of South Africa’s population of nearly 50 million people. Furthermore, the success rate of black aspiring engineers is much lower than for whites. For the 2000 cohort of engineering students 64% of white students but only 32% of black students obtained degrees after 5 years of study (Scott et al. 2007).

In 1994 the School of Engineering at the University of Pretoria initiated a 5-year programme in which students spread the load of the first two years over three years (the “slow stream” model). Extra tutorials were available in certain first year subjects. A subset of the students, those who needed the most mathematics and language support, took a foundation course comprising two, one semester modules, in the first year called Professional Orientation. This 5-year programme did not meet the Department of Education’s requirements to be classified as an extended degree programme. It also had the disadvantage that students struggled to cope with a full, mainstream load in their fourth year after having had a much lighter load in their first three years.

Figure 1. Graduation rates in Engineering for the 2002 cohort of students

Figure 1 shows the performance of the 2002 cohort of Engineering students at the University of Pretoria. The overall graduation rate after seven years for students on the 5-year extended degree program (54%) was similar to that for students in the mainstream 4-year program (57%). However, only 35% of black students on the 5-year program graduated within seven years of first registration. Although this is nearly twice the graduation rate for black students on the 4-year program, the attrition rate is too high to meet South Africa’s need for equity and for engineers.

In 2009 the first students to have written the new National Senior Certificate (NSC) at the end of Grade 12 entered South African Higher Education Institutions (HEIs). Anecdotal evidence from first year science and mathematics lecturers around South Africa indicated that these students were less able to cope with first year courses than their predecessors. A study carried out at the University of the Witwatersrand showed that student performance in mathematically-based courses decreased significantly (Hunt et al. 2010).

In order to try to avert large-scale failures, at the end of the first semester a letter was sent to all 1100 first year Engineering students advising them to transfer to the 4-year BSc programme if they had failed three or more subjects. The 4-year BSc is an extended degree programme in which the contents of the first semester of the mainstream (3-Year) BSc are spread out over three semesters and integrated with foundation level work where necessary.
In the 4-year BSc programme the students would be part of classes of 40 instead of lecture groups of 500, and would receive more foundation-level support. If they did well enough at the end of the year they would have the possibility of re-entering the BEng programme. Information obtained from these students helped inform the design of a new extended degree programme.

In this paper I will describe the design of the new extended degree programme in engineering and present preliminary results from the end of the first year of implementation.

**Design of the Engineering Augmented Degree Programme (ENGAGE)**

In October of 2009 a questionnaire was administered to the 115 students who had voluntarily transferred from the BEng to the 4-year BSc programme, asking them, amongst other things, about their experiences in the first semester in the BEng. Sixty responses were received, which are summarised in Table 1.

**Table 1. Responses to a questionnaire about 1st year engineering students’ 1st semester experiences (N=60)**

<table>
<thead>
<tr>
<th>Question</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>The amount of work I had to do was</strong></td>
<td></td>
</tr>
<tr>
<td>Much more than I expected</td>
<td>18</td>
</tr>
<tr>
<td>More than I expected</td>
<td>37</td>
</tr>
<tr>
<td>About what I expected</td>
<td>5</td>
</tr>
<tr>
<td>Less than I expected</td>
<td></td>
</tr>
<tr>
<td>Much less than I expected</td>
<td></td>
</tr>
<tr>
<td>Much more than I could cope with</td>
<td>13</td>
</tr>
<tr>
<td>More than I could cope with</td>
<td>23</td>
</tr>
<tr>
<td>About what I am able to cope with</td>
<td>22</td>
</tr>
<tr>
<td>Less than I am able to cope with</td>
<td>1</td>
</tr>
<tr>
<td>Much less than I am able to cope with</td>
<td></td>
</tr>
<tr>
<td><strong>The speed at which the work was covered was</strong></td>
<td></td>
</tr>
<tr>
<td>Much faster than I expected</td>
<td>22</td>
</tr>
<tr>
<td>Faster than I expected</td>
<td>27</td>
</tr>
<tr>
<td>About what I expected</td>
<td>10</td>
</tr>
<tr>
<td>Slower than I expected</td>
<td></td>
</tr>
<tr>
<td>Much slower than I expected</td>
<td></td>
</tr>
<tr>
<td>Much faster than I am comfortable with</td>
<td>16</td>
</tr>
<tr>
<td>Faster than I am comfortable with</td>
<td>29</td>
</tr>
<tr>
<td>About what I am comfortable with</td>
<td>14</td>
</tr>
<tr>
<td>Slower than I can cope with</td>
<td>1</td>
</tr>
<tr>
<td>Much slower than I can cope with</td>
<td></td>
</tr>
<tr>
<td><strong>The level of difficulty of the work was</strong></td>
<td></td>
</tr>
<tr>
<td>Much harder than I expected</td>
<td>14</td>
</tr>
<tr>
<td>Harder than I expected</td>
<td>34</td>
</tr>
<tr>
<td>About what I am expected</td>
<td>12</td>
</tr>
<tr>
<td>Easier than I expected</td>
<td></td>
</tr>
<tr>
<td>Much easier than I expected</td>
<td></td>
</tr>
<tr>
<td>Much harder than I am comfortable with</td>
<td>8</td>
</tr>
<tr>
<td>Harder than I am comfortable with</td>
<td>32</td>
</tr>
<tr>
<td>About what I am comfortable with</td>
<td>19</td>
</tr>
<tr>
<td>Easier than I am able to cope with</td>
<td></td>
</tr>
<tr>
<td>Much easier than I am able to cope with</td>
<td></td>
</tr>
</tbody>
</table>
The amount of support I got from lecturers was

<table>
<thead>
<tr>
<th>Amount of Support</th>
<th>5</th>
<th>16</th>
<th>31</th>
<th>7</th>
</tr>
</thead>
<tbody>
<tr>
<td>More than I expected</td>
<td>1</td>
<td>3</td>
<td>13</td>
<td>29</td>
</tr>
<tr>
<td>About what I expected</td>
<td>2</td>
<td>13</td>
<td>32</td>
<td>12</td>
</tr>
<tr>
<td>Less than I expected</td>
<td>1</td>
<td>3</td>
<td>13</td>
<td>29</td>
</tr>
<tr>
<td>Much less than I expected</td>
<td>1</td>
<td>3</td>
<td>13</td>
<td>29</td>
</tr>
</tbody>
</table>

| The amount of support I got from lecturers was | 1 | 3 | 13 | 29 | 14 |
| More than I needed | 1 | 3 | 13 | 29 | 14 |
| About what I needed | 2 | 13 | 32 | 12 |
| Less than I needed | 1 | 3 | 13 | 29 | 14 |
| Much less than I needed | 1 | 3 | 13 | 29 | 14 |

<table>
<thead>
<tr>
<th>The way I organized my time was</th>
<th>Excellent</th>
<th>Good</th>
<th>Satisfactory</th>
<th>Poor</th>
<th>Very poor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excellent</td>
<td>1</td>
<td>2</td>
<td>13</td>
<td>32</td>
<td>12</td>
</tr>
<tr>
<td>Good</td>
<td>5</td>
<td>16</td>
<td>31</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Satisfactory</td>
<td>1</td>
<td>3</td>
<td>13</td>
<td>29</td>
<td>14</td>
</tr>
<tr>
<td>Poor</td>
<td>1</td>
<td>3</td>
<td>13</td>
<td>29</td>
<td>14</td>
</tr>
<tr>
<td>Very poor</td>
<td>1</td>
<td>3</td>
<td>13</td>
<td>29</td>
<td>14</td>
</tr>
</tbody>
</table>

Students were also asked to summarise their experiences as a first year engineering student. The responses below indicate several of the most common sentiments:

Well I socialised too much in the first semester and that was the reason for my poor marks.

When coming to the university I thought I was gifted academically and could handle all the work. But within two months my positive attitude turned into a negative one. No matter how much effort I put in, nothing seemed to work.

I wasted my own time because I didn’t study.

I enjoy it very much, the subjects and classes, but I was new to student life and didn’t study hard. Work is hard work and is done very fast. Self study is very important.

I was relatively enthusiastic at first but, this feeling waned as I was confronted with the downward spiral of failure.

These responses indicate that for most of the students there was too much work that was too hard and came too fast with too little support. In addition, most students did not manage their time well. Poor initial performance decreased students’ motivation. The design of ENGAGE needed to address these issues.

In the early 1990s I was Coordinator of the Science Foundation Programme at the then University of Natal, one of the first such programmes in South Africa. At the time, we observed that there were six factors that affected science students’ performance, namely, background knowledge, attitudes, behaviours, cognitive skills, practical skills and metacognitive skills (Grayson 1996). The Science Foundation Programme was designed to address all of these factors. In designing the ENGAGE programme, these factors were also considered.

The ENGAGE programme, however, is subject to constraints that were not present in the early 1990s. In 2006 the Minister of Education declared that in future there could be no stand-alone foundation courses—all foundational provision had to be incorporated into formal extended degree programmes comprising credit-bearing courses. At the University of Pretoria these programmes are no longer reserved for black students only. Furthermore, student numbers are very large and staffing costs have risen enormously along with the cost of living over the past two decades, so it is no longer possible to provide the intensive small group teaching that characterised foundation programmes of the 1990s.

After taking all of these things into consideration, five design principles were articulated:

1. Students should be supported in making the transition from high school to university.
2. Student workload (time students spend working) should be high throughout.

3. The volume of work (amount of content covered) should be low initially and increase over time.

4. Support should be high initially and decrease over time.

5. Students should encounter familiar subjects early in the program, less familiar subjects later on.

In Vygotsky’s terms (Cole 1985), high school and university can be viewed as different cultural milieus, so adjusting to university can be seen to be a process of enculturation. Student success is more likely if this process is recognised and facilitated, hence the need for principle 1. A developmental programme, by definition, must place increasing demands on students over time. Vygotsky (quoted in Wertsch and Stone 1985) says,

> Instruction is good only when it proceeds ahead of development, when it awakens and rouses to life those functions that are in the process of maturing or in the zone of proximal development.

Thus the volume and difficulty of the work should increase over time, while support needs to decrease (principles 3 and 4). In principle 2, workload is operationally defined as the time students spend working, which is conceptually different from the volume of work to be covered. The workload needs to be high from the beginning and throughout the programme in order to build up students’ mental stamina and ability to maintain time on task, something many present day students seem to struggle with. Principle 5 relates to the well-known pedagogical principle that students learn better when new information is related to what they already know. Ausubel (1968) wrote, “The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly.”

ENGAGE is an augmented degree programme. It consists of mainstream modules augmented by developmental modules. In Year 1 there are two kinds of developmental modules, additional modules and Professional Orientation. Each 16-credit mainstream semester module, e.g. Physics, is accompanied by an 8-credit additional module, e.g. Additional Physics. The curricula of the additional modules have three foci—background knowledge (assumed to be in place by the mainstream lecturer), conceptual understanding and problem-solving and other cognitive skills development. Professional Orientation is a skills-based foundation course comprising two one-semester modules. The curriculum is structured around projects and contextualised within engineering, for example, reading assignments include articles from Engineering News. Reading, writing and presentation skills, facility with information technology, life and academic skills, teamwork, technology and simple programming in Logo are all addressed. In Year 2 additional modules also accompany some of the modules.

In the developmental modules, students are assisted in making the transition to university, developing the attitudes and behaviours of successful students and improving their metacognitive skills by means of compulsory attendance, weekly assignments that are submitted and marked, and teaching in groups of 50 by a lecturer plus a tutor as opposed to the mainstream lectures of 500 students.

Table 2 shows how the volume of work and level of difficulty, indicated by the number of credits and level of the modules, of the ENGAGE programme compares with the 4-year programme. The unfamiliarity of the level 100 engineering modules adds another dimension to the level of difficulty for ENGAGE students in Year 2.
Results of the first year

In 2010, the first year of the programme, 305 students registered for ENGAGE. When the change was made from the old Senior Certificate to the new National Senior Certificate, it was unclear how to set the admission criteria into various university programmes. The School of Engineering at the University of Pretoria chose to make the minimum marks required for entry into the 4-year BEng programme 70% for Mathematics and 60% for Physical Sciences. The minimum marks for entry into the ENGAGE programme were set 10% lower, i.e. 60% for Mathematics and 50% for Physical Sciences. About one quarter of the students in ENGAGE opted to register for ENGAGE although they met the entry requirements for the 4-year BEng programme. Figure 2 shows the marks obtained in Grade 12 Physical Sciences and Mathematics for the 2010 ENGAGE students. This figure shows that the majority (67%) of the ENGAGE students met the mathematics entry requirement for the 4-year programme.

Table 2. Comparison of the structure of the ENGAGE and the 4-year BEng programmes

<table>
<thead>
<tr>
<th></th>
<th>ENGAGE</th>
<th></th>
<th>4-Year Programme</th>
</tr>
</thead>
<tbody>
<tr>
<td>YEAR 1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mainstream Science (level 100)</td>
<td>64</td>
<td>Mainstream Science and Eng (level 100)</td>
<td>144</td>
</tr>
<tr>
<td>Developmental</td>
<td>48</td>
<td></td>
<td></td>
</tr>
<tr>
<td>YEAR 2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mainstream (level 100 + one 200)</td>
<td>96</td>
<td>Mainstream (level 200)</td>
<td>144</td>
</tr>
<tr>
<td>Developmental</td>
<td>32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>YEAR 3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mainstream (level 200)</td>
<td>128</td>
<td>Mainstream (level 300)</td>
<td>144</td>
</tr>
<tr>
<td>YEAR 4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mainstream (level 300)</td>
<td>144</td>
<td>Mainstream (level 400)</td>
<td>152/160</td>
</tr>
<tr>
<td>YEAR 5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mainstream (level 400)</td>
<td>152/160</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 3 shows the end of year results for ENGAGE students, broken down by race and gender. In order to proceed, students must pass at least 70% of the credits required in Year 1 of the programme. The overall proceed rate was 58.4%. The proceed rate for black students, 71.2%, was much higher than for white students, 52.6%. Student success depends, amongst
other things, on attitude and ability. Anecdotal evidence from ENGAGE lecturers indicates that a number of the white students showed a negative attitude towards the programme and did not put in much effort. It is also likely that some of the white students do not have what is needed to succeed in engineering, since, even after attending good schools they failed to meet the entry criteria for the mainstream BEng programme. By contrast, many of the black students come from academically disadvantaged backgrounds and were able to succeed when provided with good quality teaching and support.

Figure 2. Grade 12 Physical Sciences and Mathematics marks for 2010 ENGAGE students

These results should be compared with students who entered the old 5-year engineering programme in 2009. At the end of 2009 of the 244 students the number who proceeded to Year 2 to was 111 (45.5%). Of the total enrolled white students 40/105 (38.1%) proceeded and of the black students 66/133 (49.6%) proceeded. (It is not meaningful to make comparisons before 2009 because both the school and the university curricula changed.)

Table 3. Final results for 2010 ENGAGE students

<table>
<thead>
<tr>
<th></th>
<th>exclude</th>
<th>withdrew</th>
<th>proceed</th>
<th>TOTAL</th>
<th>% proceed of registered</th>
<th>% proceed of continued*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>24</td>
<td>8</td>
<td>79</td>
<td>111</td>
<td>71.2</td>
<td>76.7</td>
</tr>
<tr>
<td>male</td>
<td>10</td>
<td>8</td>
<td>58</td>
<td>76</td>
<td>76.3</td>
<td>85.3</td>
</tr>
<tr>
<td>female</td>
<td>14</td>
<td>21</td>
<td>35</td>
<td>60</td>
<td>60.0</td>
<td>60.0</td>
</tr>
<tr>
<td>Indian</td>
<td>6</td>
<td>3</td>
<td>4</td>
<td>13</td>
<td>30.8</td>
<td>40.0</td>
</tr>
<tr>
<td>male</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>10</td>
<td>40.0</td>
<td>57.1</td>
</tr>
<tr>
<td>female</td>
<td>3</td>
<td>1</td>
<td>0</td>
<td>0</td>
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<td>0</td>
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<tr>
<td>Coloured</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>50.0</td>
<td>66.7</td>
</tr>
<tr>
<td>male</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>50.0</td>
<td>66.7</td>
</tr>
<tr>
<td>female</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>White</td>
<td>51</td>
<td>33</td>
<td>93</td>
<td>177</td>
<td>52.6</td>
<td>64.6</td>
</tr>
<tr>
<td>male</td>
<td>42</td>
<td>31</td>
<td>81</td>
<td>154</td>
<td>52.6</td>
<td>65.9</td>
</tr>
<tr>
<td>female</td>
<td>9</td>
<td>2</td>
<td>12</td>
<td>23</td>
<td>52.2</td>
<td>57.1</td>
</tr>
<tr>
<td>TOTAL</td>
<td>82</td>
<td>45</td>
<td>178</td>
<td>305</td>
<td>58.4</td>
<td>68.5</td>
</tr>
</tbody>
</table>

*% of students who could proceed relative to those who did not withdraw
Table 4 shows the end of year performance for all first year engineering students who registered for the first time in 2010. The table shows that a smaller percentage of white ENGAGE students were able to proceed than white students overall, while the percentage of black (African) ENGAGE students who could proceed was much higher than for black students overall. In addition, although only 36% of black students were in ENGAGE, the ENGAGE students accounted for 43% of the black students who could proceed and 54% of the black students who passed all of their first year subjects and could proceed to Year 2 (although we recognise that the load was lighter for ENGAGE students).

In October 2010 a questionnaire was administered to ENGAGE students. Table 5 summarises responses to questions related to attitudes and behaviours. A 4-point Likert scale was used. In two questions where there was a large difference in responses the responses are broken down by race, where black means African. (The Indian and Coloured student numbers were very small and so were not shown separately.)

**Table 4.** End of year results for all first year first time registered students in engineering

<table>
<thead>
<tr>
<th>Race</th>
<th>Registered</th>
<th>Proceed yr 2*</th>
<th>Proceed**</th>
<th>Total can continue</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black (all)</td>
<td>310</td>
<td>74</td>
<td>109</td>
<td>35.2%</td>
</tr>
<tr>
<td>White (all)</td>
<td>716</td>
<td>253</td>
<td>234</td>
<td>32.7%</td>
</tr>
<tr>
<td>Indian (all)</td>
<td>65</td>
<td>18</td>
<td>20</td>
<td>30.8%</td>
</tr>
<tr>
<td>Black (ENGAGE)</td>
<td>111</td>
<td>40</td>
<td>39</td>
<td>35.1%</td>
</tr>
<tr>
<td>White (ENGAGE)</td>
<td>177</td>
<td>47</td>
<td>46</td>
<td>25.9%</td>
</tr>
<tr>
<td>Indian (ENGAGE)</td>
<td>13</td>
<td>1</td>
<td>3</td>
<td>23.1%</td>
</tr>
<tr>
<td>Black (non-ENGAGE)</td>
<td>199</td>
<td>34</td>
<td>70</td>
<td>35.2%</td>
</tr>
<tr>
<td>White (non-ENGAGE)</td>
<td>539</td>
<td>206</td>
<td>188</td>
<td>34.9%</td>
</tr>
<tr>
<td>Indian (non-ENGAGE)</td>
<td>52</td>
<td>18</td>
<td>20</td>
<td>38.5%</td>
</tr>
</tbody>
</table>

*passed everything  
**have to repeat one or more modules

The questionnaire responses show that most of the concerns expressed by the students who transferred from Engineering to the 4-year BSc programme in 2009 were not concerns for ENGAGE students. However, as with the final marks, questionnaire responses indicate that African students benefitted more from being part of ENGAGE than white students. In terms of the results shown in Table 5, it is likely that for black students the transition from school to university was more difficult and the level of life skills was lower than for white students given the nature of the schools many black students attended and the relatively poorer communities from which many of them come.
Table 5. Students who agreed or strongly agreed on end of semester evaluation (N=228)

<table>
<thead>
<tr>
<th>Question</th>
<th>Percent (Number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Being an ENGAGE student has helped me make the transition from school to university (black 89%, White 72%)</td>
<td>79 (180)</td>
</tr>
<tr>
<td>I felt there was someone I could go to if I had academic problems during the year</td>
<td>80 (183)</td>
</tr>
<tr>
<td>I got the support I needed this year</td>
<td>79 (181)</td>
</tr>
<tr>
<td>I kept up to date with my work this semester</td>
<td>77 (175)</td>
</tr>
<tr>
<td>I coped with the workload this semester</td>
<td>80 (183)</td>
</tr>
<tr>
<td>I learned useful life skills in ENGAGE this semester (African 84%, White 53%)</td>
<td>66 (151)</td>
</tr>
<tr>
<td>After this semester I still want to be an engineer</td>
<td>90 (206)</td>
</tr>
</tbody>
</table>

Conclusion

While South Africa needs to substantially increase its production of engineers in order to maintain and develop infrastructure and the economy as a whole, far too few of the entering students are succeeding in engineering degrees in a reasonable time. At the University of Pretoria, over a number of years approximately one third of students complete their degree in four years, one third in more than four years and the other third leave the programme. For black students the figures are much worse. Results from the first cohort of ENGAGE students in their first year suggest that the programme is helping students succeed, especially black students. It seems as if ENGAGE may be a useful tool for redress. Whether this success will be maintained in higher years remains to be seen. We shall really only be able to measure the success of the programme in a few years’ time when ENGAGE students start completing their degrees.

While good curricula and a supportive environment are important for promoting student success, success is not possible unless there is good alignment between the profile of entering students and what the university is able to provide. In addition to developing good programmes, universities need a reliable means of selecting students who are capable of succeeding, and then placing them in programmes that will match their abilities and level of preparation. In the three years since the National Senior Certificate was introduced, universities have been trying to establish the predictive value of NSC marks. Many, including the University of Pretoria, are using the National Benchmark Tests, NBT (2011), as an additional source of information to guide placement decisions. In 2010 only potential ENGAGE students applying for engineering had to write the NBT, and the admission criteria to the mainstream programme were quite low. In 2011, a three-tiered admission and placement system was introduced, summarised in Table 6.
Table 6. Admission criteria Engineering for 2011

<table>
<thead>
<tr>
<th>Programme</th>
<th>Points</th>
<th>Min Maths</th>
<th>Min Phy Sc</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-year</td>
<td>36</td>
<td>80%</td>
<td>70%</td>
</tr>
<tr>
<td>4-year or ENGAGE</td>
<td>30-35 +NBT</td>
<td>70%</td>
<td>60%</td>
</tr>
<tr>
<td>ENGAGE only</td>
<td>25-29 +NBT</td>
<td>60%</td>
<td>50%</td>
</tr>
<tr>
<td>Maybe 4-yr BSc</td>
<td>&lt;30 + NBT</td>
<td>50%</td>
<td>50%</td>
</tr>
</tbody>
</table>

After the positive experience of students who transferred to the 4-year BSc programme in 2009, the School of Engineering at the University of Pretoria has been collaborating with the Faculty of Natural and Agricultural Sciences to place students in programmes offered by the two faculties that best meet their level of preparation. Since ENGAGE is an augmented degree programme, only students who are ready to take mainstream modules, albeit a reduced number, will succeed. In the 4-year BSc, students spend three semesters covering the equivalent of the first semester of the mainstream basic science modules, with foundational work integrated as needed. All teaching is done in groups of about 40 students. The 4-year BSc is more appropriate for students who need more foundation level support. If students do well enough, it is possible to transfer to engineering at the end of either two or three semesters. Thus there are now multiple routes into engineering that provide differing levels of support.

At this stage, we do not have a formalised system for recommending students to different programmes on the basis of their NBT and NSC marks, but try to qualitatively assess students' level of preparation, using the three categories of the NBT as a guide. In the second semester we plan to do correlations between NBT, NSC and first semester basic sciences results, after which we hope to have a clearer idea of how to effectively use the NBT for placement.

We hope that better placement decisions, when combined with good curricula and career guidance, will lead to ever greater student success in the future.

References


Hunt, K., Ntuli, M., Rankin, N., Schöer, V. & Sebastiao, C (2010). Comparability of NSC mathematics scores and former SC mathematics scores: How consistent is the signal across time? Presented at the “Mind the Gap” Forum of the Academy of Science, 21-22 October 2010, Cape Town. [http://www.assaf.org.za/?s=Mind+the+Gap&amp;x=0&amp;y=0](http://www.assaf.org.za/?s=Mind+the+Gap&amp;x=0&amp;y=0)


Predicting Academic Performance in Engineering Studies

Elza Hattingh
Faculty of Engineering, North-West University, South Africa
elza.hattingh@nwu.ac.za

Abstract
Most engineering faculties in South Africa use the National Senior Certificate (NSC) as a basis for selecting potential students. The predictive value of the NSC is a critical issue, and many institutions investigate alternative mechanisms in order to identify candidates that will be successful in their studies. The National Benchmark Tests (NBT), and the North West University engineering test (NWU-ET) are similar initiatives.

The NWU engineering test battery is a set of computer tests developed by the academic staff of the faculty of engineering at NWU. The tests aim to identify learners with the skills needed for engineering studies, and have been developed over the last four years. The NWU_ET do not retest school subject material, but the ability of learners to apply higher cognitive skills using grade 11-subject material.

This presentation will present NSC, NBT and the NWU engineering selection battery data, and show how they correlate with each other, as well as with student progress.

Our results show that the NSC and the NBT correlate well with the results of the first academic year at university. The predictive value of NSC and the NBT decreases with subjects that require higher cognitive skills such as insight, logical reasoning, generalization and application skills. There is, however, a better correlation between the NWU-ET and these subjects.

Most studies on the success rate of students at university focus only on the first year. The aim of the NWU-ET is to predict academic success of our students up to the final year. A second aim is to broaden access by identifying candidates for engineering studies from the pool of applicants with average and even lower than average school marks.

Introduction
Using entry examinations as part of a selection process has a long history in South Africa. It had been expected from students enrolling for medicine, law, journalism, drama and architecture to write an entry examination for a long time. However, it became common practice during the last decade in some other faculties because of a number of reasons:

- The number of applicant exceeded the number of positions at Higher Education Institutions (HEIs): The growth in student numbers exceeded the development of capacity in most institutions, and it became important to have a mechanism to identify applicants with the best likelihood of academic success. HEIs are under pressure from government to increase pass rates and throughput, and are funded accordingly.

- Students enrolling at universities are more diverse and come from a wide range of cultural and social backgrounds. HEIs have to accommodate these students and ensure that they have the support in order to succeed. It became important to understand and measure the level of the students

- The DoE implemented major changes to the curriculum content and composition of programs in schools. The changes constituted a move away from an input/content-
based curriculum and assessment to an outcomes based curriculum and assessment with limited options to select subjects. A new secondary school exit qualification was also implemented in the year 2006.

The first applicants with the [new] National Senior Certificate (NSC) were enrolled at engineering faculties in 2009. The HEIs were not sure of the knowledge and level of preparedness of applicants, and students experienced problems with first year mathematics and science. Engineering faculties, as well as the media, reported that the 2009 mid-year mathematics pass rate of this group was below expectation (Wolmarans et al, 2010). Volker Schoër (2009) posited that the NSC was, on average, inflated by 14 points (as cited in Holman, 2009). It was clear that the NSC had not been benchmarked against the previous matric qualification, and tertiary institutions were unsure how to interpret the NSC results.

With these problems in mind, a national workgroup developed the NBT in order to assist HEI to interpret the NSC results. According to the HESA project proposal of May 2006, the purpose of the NBT is fourfold:

- To assess entry-level academic and quantitative literacy and mathematics proficiency of students;
- To assess the relationship between entry level proficiencies and school-level exit outcomes;
- To provide a service to HE institutions requiring additional information in the admission and placement of students; and
- To inform the nature of foundation courses and curriculum responsiveness.

(Griesel, H, May 2006, p 11)

The purpose of the NBT is therefore mainly to benchmark and re-test/calibrate the matric and assess the preparedness of students.

**The purpose of developing the Engineering Entrance Test**

Although the NBT is useful to calibrate the matric results and to determine if an applicant is prepared to study at a tertiary level it was not designed to test the aptitudes and skills needed for academic success in a specific programme. Because of the need to improve access, throughput and pass rates, it became clear to the Faculty of Engineering that we needed a tool to predict academic success during all the years of the academic program leading to success in a career.

The following diagrams will explain the difference:

In an ideal system there existed a linear, continuous relationship between school, university, and work. Schools aim to prepare students for university (Figure 1) and universities received applicants who are ready for university studies and able to cope with the level and volume of content. In addition, industry adapts to the output of the university system, and spend time and resources training newly qualified graduates in industry.

This is, however not the case in the current system. At present, there are two major trends that influence engineering faculties.

Firstly, school leavers are poorly prepared to process the level and volume of work needed in engineering academic programs. Yeld (2009) states that

The challenge faced by higher education institutions in relation to Mathematics is clearly enormous, and with the current emphasis on the production of graduates in scarce skills areas such as Engineering and Science, the need for curriculum responsiveness and remediation in this area is evident ... higher education is
facing a very serious problem in respect of the mathematics knowledge and manifest ability of its entering classes.

Figure 1. Transition from school to university and university to industry in an ideal system

Secondly, the work environment changed dramatically as companies became leaner, flatter, and more competitive, and the need for high-level work-ready human resources grew dramatically. Engineering graduates need to be internationally competitive much faster. Industry has less resources and time to train young, recently qualified engineers.

The preparedness of applicants varies from year to year and is lower than expected, while the industry expects internationally competitive engineering graduates. The university is forced to continually adapt to varying input quality while expected to deliver graduates on an increasingly higher output level.

The following diagram shows the two effects:

The high failure rates in first year courses forced engineering faculties to adapt and to accommodate the profile of enrolling students. Lecturers are using creative ways to facilitate learning and faculties support struggling students through well-designed interventions. This intense focus on first-year teaching/learning lead to improved pass rates. It is however important to note that a positive correlation between matric marks and first year performance is not an indication of matric being a good predictor for success in the first year, but rather an indication of the effectiveness of the university to adapt to the new profile of current students through customised interventions.

For example, in 2009, the engineering students at the NWU had disappointing mid-year results in Mathematics, as was the case in the rest of the country (Wolmarans et al, 2010). The pass rate for Mathematics 1 at the NWU in 2009 was 68%. During the first semester of 2010 the mathematics lecturers developed a high-intensity strategy to support first year students, and offered a compulsory bridging course, changed their approach and tempo of work, and gave extra classes during the semester. With this intensified approach, the pass rate for the first semester Mathematics of 2010 improved to 80%. The improvement in correlation between the NSC and the first semester mathematics results between 2009 and
2010 was not because of any change in the preparedness of matric learners but rather in the way the faculty adapted to the situation.

Figure 2. The current situation at university: university has to adapt to the new student profile and prepare a student for industry.

This adaptive tracking problem leads to discontinuity in the second and third year (Figure 2). At the North West University, we now find that the failure rate during the second year at university is higher than during the first year. It is therefore important to be able to predict the students’ ability to be successful during the senior to final years of study, and beyond.

The Results of the NBT test

A group of our students wrote the NBT test during the first semester of 2010. These students wrote the NWU-ET during June of the previous year as part of the application process. We found that the NBT test correlates well with the average semester 1 mark, as does the matric Mathematics and Physical Science marks. This suggests that the first year courses were well adapted to the capabilities of the students.

The NBT Language test shows a correlation coefficient of 0.33 with the average semester one results and the NBT Mathematics test has a correlation coefficient of 0.57 with the average semester one results (Table 1).
Table 1. The NBT results are correlated with the average first semester results at university

<table>
<thead>
<tr>
<th>NBT Subtests</th>
<th>r</th>
<th>N</th>
<th>Significance p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Language</td>
<td>0.3302</td>
<td>N=301</td>
<td>p=0.000</td>
</tr>
<tr>
<td>Mathematics</td>
<td>0.5729</td>
<td>N=302</td>
<td>p=0.00</td>
</tr>
</tbody>
</table>

\( r = \) Pearson \( r \) Correlation Coefficient

There is, interestingly, a better correlation between the school results (mathematics and physical science) and the average first semester marks (Table 2).

Table 2. The NSC mark for Mathematics and Physical Science are correlated with the average first semester results at university.

<table>
<thead>
<tr>
<th>NSC subjects</th>
<th>r</th>
<th>N</th>
<th>Significance p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mathematics</td>
<td>0.6309</td>
<td>N=548</td>
<td>p=0.000</td>
</tr>
<tr>
<td>Physical Science</td>
<td>0.6312</td>
<td>N=548</td>
<td>p=0.00</td>
</tr>
</tbody>
</table>

\( r = \) Pearson \( r \) Correlation Coefficient

The NWU therefore accepts that applicants with high marks in mathematics and physical science in matric have a high probability to be successful in their first year of engineering studies.

**Engineering Selection Battery**

It is common for students who excel in science and mathematics subjects to enter undergraduate degree programs in science, medicine, engineering, and architecture. However, it is not known whether the candidates have the make-up needed to complete their studies successfully. Engineering courses are structured differently and students are expected to exhibit different behaviour from those doing traditional Natural Science courses. Srinivasa and Bassichis (2006) found that

The purpose of the physics course for engineering students is quite different from that of an introductory physics course for physics students. The purpose of the introductory mechanics course for engineering students are to provide them with (1) an understanding of the fundamental concepts of physics … and their interrelationships … (2) the ability to diagnose which of the laws to apply in a given situation (3) the ability to utilize their mathematical tools (Geometry, vector algebra and calculus) to calculate the relevant quantities and derive the resulting equations.

Physical Science and Mathematics are studied, not as ends in themselves, nor merely for the scientific insight involved, but rather as practical tools to be applied ultimately in the manipulation of the real world. Students therefore need to be able to apply these principles in order to solve real-world problems.

Regrettably, we find that students do not always demonstrate the cognitive skills needed which these subjects’ demands, and even applicants with good marks in mathematics and science in matric, do not always grasp the complexities of the concepts they need to understand. Concerns about learners’ and teachers’ understanding of subject contents were raised at the NSTF’s workshop on Science, Technology, Engineering and Mathematics (STEM) Education during April 2010. One of the outcomes discussed during the workshop was the following:
It is important to consider how learners learn rather than simply measuring the outputs in terms of examination results. Understanding should be valued, rather than just results. We should start concentrating on improving skills and abilities.

During the workshop, Brombacher (2010) emphasized a number of concerns related to mathematics education. He indicated that some teachers focus on covering the curriculum rather than on developing understanding. Faulty mathematical methods that learners use sometimes result in correct answers and learners do not understand why their answers are sometimes correct and sometimes wrong. According to Ndaba (2010), the South African public examination results are the main performance indicators of schools. Schools with the highest number of passes are reported in the media. This practice may lead to teaching for examination results and rewarding memorizing of knowledge for examination purposes instead of acquiring skills and focusing on processes.

The NWU’s Faculty of Engineering therefore decided to develop an instrument that could provide better data on success in the undergraduate engineering programme. The NWU-ET is now part of the application process and provides additional information to the selection teams.

**The NWU Engineering Test**

Engineering entrance examinations are common practice internationally. For example, India has 11 different entrance examinations based mainly on mathematics, physics and chemistry. The Student Selection Examination for undergraduate programmes in Turkey measures mainly the candidates’ verbal abilities and quantitative abilities. The purpose of these tests is to determine performance of students during their freshman year (Rende et al, 2006).

In contrast, the aim of the NWU Engineering test is to predict success throughout the engineering programme, and does not aim to re-test or benchmark the matric. The test was developed by engineering educators for engineering students, and closely simulates the engineering courses that the applicants applied for. The test evaluates the skills and competence needed to do well in the engineering programmes and to thrive in industry. The questions were therefore designed to test mainly higher order cognitive processes such as comprehension, application, and generalization, identification of solutions, reasoning, analysing, and problem solving.

The Natural Science faculty, the School of Languages and the Engineering faculty are involved in the development of the test. The test includes the following subtests: Algebra, Geometry, Physics, and Chemistry.

The comprehension test is designed to evaluate a student’s ability to comprehend and use engineering textbooks. It does not attempt to test English language competency, but is focused on the skills needed to critically read and understand new, complex concepts as discussed in a typical engineering textbook.

In the numerical skills/problem solving test, new concepts are introduced that the applicant has never encountered before. We test the applicants’ numerical fluency and we evaluate the applicants’ ability to read and understand unfamiliar concepts and their ability to manipulate new concepts productively.

The three engineering tests (Chemical, Electrical and Mechanical Engineering tests) developed by engineers, aims to measure aptitudes in engineering as a career. The contents of these three tests are based on real life problems within the different fields, using their existing
knowledge base. Applicants are therefore assessed on their ability to apply knowledge in new situations and to reach new solutions. All the necessary information needed to answer a question is usually given as part of the question. This is because the aim of the test is not to test knowledge. They are being tested on their problem solving skills, verbal and three-dimensional reasoning skills, their logical, analytical, and critical thinking skills.

The engineering test is a computer-based test using multiple-choice questions. There are between 20 and 25 questions per subtest with a total of 182 questions. The time is limited to 35 minutes per subtest. We do not use a pool of questions. All the applicants receive the same questions to ensure that they are tested on the same level of complexity. Applicants write the test under the same writing conditions, have the same automated time limits, the test is marked automatically and objectively with no possible marking mistakes.

The Selection process

A selection committee of lecturers from the engineering departments with the school director selects applicants. The selection committee takes all relevant information of the applicant into account. This includes the matric results, other matric subjects, career guidance reports, CV information, work experience, and the results of the engineering test. Information from the NBT (as a way to benchmark the matric results) is also welcome.

The purpose of the Engineering Test is to broaden access and to provide additional information on learners who would not previously have been considered for engineering because of average or lower than average matric marks.

The correlation between the NWU-ET and first year performance

The correlation between the NWU-ET, Algebra, Geometry, Physics and Chemistry sub tests with the first year performance is as follows:

Table 3. The correlation between the Engineering subtests and the average first semester marks at university.

<table>
<thead>
<tr>
<th>Engineering subtests</th>
<th>r</th>
<th>N</th>
<th>Significance p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Algebra</td>
<td>0.5249</td>
<td>N=181</td>
<td>p=.000</td>
</tr>
<tr>
<td>Geometry</td>
<td>0.5446</td>
<td>N=178</td>
<td>p=.000</td>
</tr>
<tr>
<td>Chemistry</td>
<td>0.4406</td>
<td>N=178</td>
<td>p=.000</td>
</tr>
<tr>
<td>Physics</td>
<td>0.6105</td>
<td>N=176</td>
<td>p=0.00</td>
</tr>
</tbody>
</table>

$r =$ Pearson r Correlation Coefficient

Table 4 shows the correlation between the first year engineering subjects, the NBT test, and the average score on the NWU-ET. It is clear that there is little difference in the strength of correlation between the NWU_ET the NBT, and the first year subjects.
Table 4. Correlation between specific first year subjects and the NBT test and Engineering Test.

<table>
<thead>
<tr>
<th>Subject</th>
<th>Mathematics first year</th>
<th>Physics first year</th>
<th>Chemistry first year</th>
<th>Statistics first year</th>
<th>Computer Science first year</th>
</tr>
</thead>
<tbody>
<tr>
<td>NBT Language Score</td>
<td>r = 0.2822* N=298</td>
<td>0.3163* N=294</td>
<td>0.2036* N=182</td>
<td>0.3133* N=52</td>
<td>0.3841* N=81</td>
</tr>
<tr>
<td>NBT Maths Score</td>
<td>r = 0.569* N=299</td>
<td>0.6247* N=295</td>
<td>0.5061* N=182</td>
<td>0.5094* N=53</td>
<td>0.5177* N=81</td>
</tr>
<tr>
<td>Engineering Test Average</td>
<td>r = 0.6224* N=279</td>
<td>0.6105* N=176</td>
<td>0.4619* N=218</td>
<td>0.5266* N=42</td>
<td>0.5194* N=95</td>
</tr>
</tbody>
</table>

*r = Pearson r Correlation Coefficient
N = sample size
*Marked correlations are significant: p = 0.000

We found a strong correlation between the NWU_ET and individual subjects such as the subtest: Physics with FSKN111 (Physics 1) at university (Graph 1).

Graph 1. Correlation between the average mark on the NWU_ET and Physics 1 at university.
r =0.7081; N = 81 ; p = .000

The strong correlations between the NWU_ET and the first year Applied Mathematics, Mathematics, Chemistry, and Chemical Engineering can be seen in Table 5.
Table 5. Population: students with distinctions in both Mathematics and Physical Science in matric. Correlation between the Engineering subtests and university subjects.

<table>
<thead>
<tr>
<th>Senior level subjects</th>
<th>$r$</th>
<th>$N$</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>TGWS121</td>
<td>0.6289</td>
<td>N=75</td>
<td>p=.000</td>
</tr>
<tr>
<td>WISK111</td>
<td>0.7030</td>
<td>N=79</td>
<td>p=.000</td>
</tr>
<tr>
<td>CHEM111</td>
<td>0.6197</td>
<td>N=80</td>
<td>p=.000</td>
</tr>
<tr>
<td>CEMI112</td>
<td>0.5236</td>
<td>N=81</td>
<td>p=.001</td>
</tr>
<tr>
<td>CEMI212</td>
<td>0.5105</td>
<td>N=48</td>
<td>p=.000</td>
</tr>
<tr>
<td>CHEN222</td>
<td>0.6197</td>
<td>N=79</td>
<td>p=.000</td>
</tr>
<tr>
<td>CEMI323</td>
<td>0.5194</td>
<td>N=45</td>
<td>p=0.01</td>
</tr>
<tr>
<td>EERI212</td>
<td>0.5237</td>
<td>N=73</td>
<td>p=.000</td>
</tr>
</tbody>
</table>

$r =$ Pearson $r$ Correlation Coefficient

It is interesting to see that the Engineering Test correlates well with academic performance in the senior level subjects such as CEMI212, CHEN222, EERI212 and CEMI323 (Table 5). This suggests that the NWU_ET might be able to predict academic success of senior students. This will be elaborated on in the next section.

The correlation between the NWU_ET and long-term academic success.

We found by further investigation that some applicants with excellent (>80%) matric mathematics and physical science marks did well in the NWU_ET (Group A: NWU_ET ≥65%). Another group of students with excellent matric marks did poorly (Group B: NWU_ET<65%). We found a very strong correlation between the NWU_ET scores of Group A and their subsequent performance in the engineering programme. Students from Group B, who scored lower than 65% on the Engineering test, performed poorer in the senior years of studies. Graph 2 shows the difference in the average year marks of the two groups of students in their first and second year of studies.
Graph 2. Year marks at university of students with distinctions in matric in Mathematics and Physics but differed in performance on the Engineering Test.

<table>
<thead>
<tr>
<th>Students with distinctions in both Mathematics and Physics in matric</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image" alt="Graph showing average year mark vs. average year mark for students in different performance groups." /></td>
</tr>
</tbody>
</table>

Students with higher marks on the engineering test perform academically better during the first and second year at university and the good performance seems to remain stable. More correlations between the engineering subtests and performance in the senior engineering subjects are given in tables 6, 7 and 8 as examples:

The Numerical Skills test shows correlations with the following subjects:

**Table 6. Correlation between the Numerical Skills test senior level subjects**

<table>
<thead>
<tr>
<th>Senior level subjects</th>
<th>( r )</th>
<th>( N )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>STTK111</td>
<td>0.5266</td>
<td>N=42</td>
<td>p=.000</td>
</tr>
<tr>
<td>MATI121</td>
<td>0.5609</td>
<td>N=62</td>
<td>p=.000</td>
</tr>
<tr>
<td>CEMI212</td>
<td>0.5940</td>
<td>N=80</td>
<td>p=.000</td>
</tr>
<tr>
<td>CEMI322</td>
<td>0.4713</td>
<td>N=44</td>
<td>p=0.01</td>
</tr>
<tr>
<td>CEMI411</td>
<td>0.4816</td>
<td>N=42</td>
<td>p=.001</td>
</tr>
</tbody>
</table>

\( r = \) Pearson \( r \) Correlation Coefficient  
\( N = \) sample size

It is interesting to see that the correlation between the Numerical Skills Test and the average year mark of the students grows stronger each year (Table 7). As previously discussed, we evaluate in the Numerical Skills Test the students’ ability to learn new knowledge and to apply the knowledge in a new situation. It seems as if the students with high scores in this subtest perform well during the subsequent academic years.
Table 7. Correlation between the Numerical Test results and the average year marks in the first, second, third and fourth year of engineering studies.

<table>
<thead>
<tr>
<th>Numerical Skills Test</th>
<th>r</th>
<th>N</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td>0.2798</td>
<td>N=460</td>
<td>p=0.000</td>
</tr>
<tr>
<td>Year 2</td>
<td>0.3271</td>
<td>N=102</td>
<td>p=0.001</td>
</tr>
<tr>
<td>Year 3</td>
<td>0.3432</td>
<td>N=61</td>
<td>p=0.007</td>
</tr>
<tr>
<td>Year 4</td>
<td>0.4608</td>
<td>N=46</td>
<td>p=0.001</td>
</tr>
</tbody>
</table>

$r =$ Pearson r Correlation Coefficient

Some of the correlations between the Chemical Engineering, Electrical Engineering and Mechanical Engineering tests with senior level subjects are shown in Table 8.

Table 8. Some correlations between the Chemical Engineering, Electrical Engineering and Mechanical Engineering and senior level subjects

<table>
<thead>
<tr>
<th>Senior level subjects</th>
<th>r</th>
<th>N</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEGI111</td>
<td>0.5266</td>
<td>N=42</td>
<td>p=0.000</td>
</tr>
<tr>
<td>MATI121</td>
<td>0.5609</td>
<td>N=62</td>
<td>p=0.000</td>
</tr>
<tr>
<td>CEMI212</td>
<td>0.5491</td>
<td>N=78</td>
<td>p=0.000</td>
</tr>
<tr>
<td>CEMI311</td>
<td>0.4633</td>
<td>N=46</td>
<td>p=0.001</td>
</tr>
<tr>
<td>CEMI322</td>
<td>0.4713</td>
<td>N=44</td>
<td>p=0.01</td>
</tr>
</tbody>
</table>

$r =$ Pearson r Correlation Coefficient

N = sample size

Scores on the Chemical, Electrical and Mechanical Engineering subtests are also useful to predict an applicant’s ability to use higher cognitive skills needed in engineering on the senior academic levels. The selection committee may use these results to advise applicants how to improve their study methods and acquire skills to handle the challenging subject content in the senior years.

Continual development

The NWU_ET is updated on a yearly basis. Each question is analysed and the correlation between the question and marks in all the courses in all the programmes determined. Questions with poor correlations are exchanged with other questions.

The first cohort of students, who wrote the NWU_ET, is now in their fourth year. We therefore have data from the first year up to the mid-fourth year academic results. We plan to continue with this longitudinal study by monitoring the progress of our students, and eventually following their progress in industry.

Conclusion

We are continually tracking students as they progress in their studies, and in this paper we present some of the research results. The NWU_ET is analysed yearly on an item-by-item basis and upgraded to keep track with changes in the school environment, as well as the needs of the faculty of Engineering. The next step in the development of the test is to identify the skills and characteristics of engineers that are successful in industry and include items that evaluate these skills, attitudes, and features/characteristics.
We are aware of the fact that applicants with distinctions in mathematics and physical science have a high probability of being successful in the engineering programmes (Author, 2010). The question to be asked, however, is: Are those students necessarily successful engineers? By selecting only the academically outstanding students, will we produce the kind of engineer that the country needs? How do we identify the potentially successful engineer in the group of applicants with lower school results?

At the North-West University, we prefer not to miss our potentially talented engineers by raising our entry requirements and excluding a number of learners who may be successful in industry.

References


Engineering soft skills? My responsibility. A case study at the Nelson Mandela Metropolitan University

Hilda F Israel
Department of Applied Language Studies, Nelson Mandela Metropolitan University, South Africa
hilda.israel@nmmu.ac.za

Abstract
The academic knowledge gained through years of study qualifies one to become an engineering technologist, hopefully of the highest standard. But, does this also make one a better human being, one who exemplifies the inherent qualities of ubuntu? Does the engineering curriculum prepare one to positively engage with colleagues from diverse cultures in the work place? Are lecturers responsible for making the student aware of the soft skills essential to one’s career as an engineer? This paper reflects on the miniscule opportunity provided for the student to acquire soft skills during his/her three years of study: through the interventions provided within the Communication Skills Module. It critically evaluates and makes recommendations on the time allocated, content, delivery mode and assessment methods of this module as offered to industrial engineering students enrolled at the NMMU. Its recommendation to every engineering lecturer is simple: Yes, you are a teacher, and it is your responsibility.

Soft skills – the context
A retired South African educator, aged 80, once commented that people do not remember your status, qualifications or wealth. They do remember how you made them feel. What does it take to make people feel appreciated, respected, heard, affirmed, wanted, loved, uplifted? What is it that gives people dignity, equality and a sense of justice?

There is no one answer to these questions, but it is expected that when a student graduates from a university, he/she should be aware that it is these qualities, broadly referred to as “soft skills” that complete him/her. The academic knowledge gained through years of study qualifies an engineering technologist to be just that – a technologist, hopefully of the highest standard. But, does this also make one a better human being, one who makes people feel that they matter? Does the coursework prepare one to positively engage with people in the workplace: as an employee; as a supervisor; with colleagues from different ethnic groups/religious faiths/cultures? What about with family members; as partners; as parents; with friends? The assumption is that one learns this incidentally, along the way, from parents, religious institutions, role models, general reading. But, do we? Does society today provide this kind of positive support for the engineering student in South Africa? Is there a need for engineering graduates from the NMMU to join the workforce as people-centred, holistically developed individuals who earn the respect of others? As a lecturer to such students, one has to believe that there is.

Variyar (2009-1) identifies soft-skills as “adaptability, open-mindedness, problem solving, decision making, communication skills, self learning and knowledge discovery, empathy and team work, motivation and attitude encompassing initiative, perseverance in adversity and ability to motivate self and others.” He clarifies that soft skills include the English language (spoken and written), communication and team work, but adds that globalization has
demanded inclusion of “technical excellence, newer skills like knowledge of interacting with trans-national cultural behaviour, use of graphic communication including use of annotations with pictures, conducting walk-through using webinar sessions” Variyar (2009-1). Quality systems and processes are a result of a positive mindset and attitude, attention to details and assertiveness, including the ability to say no when appropriate. He commends integrity, honesty and forthrightness in admitting mistakes – supporting the original premise that it is qualities like these that make the engineer a better human being.

In a lecture on the importance of the development of soft skills in engineering education, Dr S Mori Vaezi-Nejad (2009-1), from London Metropolitan University, writes that his research provided overwhelming evidence that employers were not satisfied with the soft skills of graduates, necessitating the introduction of several soft skills modules focussing on employability and marketability of students. Variyar (2009-1) emphatically writes that while today’s new-generation engineering force is confident, self-sufficient, independent, knowledgeable and highly informed on social, political and environmental issues, they pose a real challenge in terms of having relevant soft skills: “Engineers, taken as a class, tend to be less endowed with soft-skills ... The highly advanced mathematical, analytical brain may not be much of a communicator... an all-rounded development of complementary human intelligences and faculties like creativity and inter-personal skills is stunted.” At the NMMU, it has become clear that in order to get these soft skills, lecturers ought to include them in daily teaching practice. Since soft skills are a part of everyday life, students do not always need a special class to learn them. Instead, they should be an intrinsic part of every lesson.

Basically, when an engineering employee with soft skills is sought, what is wanted is a well-rounded and resourceful individual. However, since soft skills cannot be overtly measured, experience is important for today’s job market. It is only over an extended period of time that one can see whether an employee really has the critical thinking and problem solving abilities claimed (University of North Carolina Tomorrow Blog, 2007-1). Soft skills focus on personality types and personal goals, not just academic knowledge of critical thinking strategies.

At university level, one cannot underestimate the value of producing graduates who possess the following skills: “teamwork, critical thinking and reasoning, oral and written communication, assembling and organizing information, innovative and creative thinking, facility with numbers and statistics, and foreign language proficiency” (University of North Carolina Tomorrow Blog, 2007-1).

The motivation behind the soft skill interventions introduced within the NMMU Communication Skills module for engineers seems to also reflect an international need. In the United Kingdom, research from industry provided evidence that employers were not satisfied with the soft skills of graduates. Module content had to be revised to make students more employable, more marketable (Mori Vaezi-Nejad, 2009-1). In the United States, engineering programs have been revised to focus on the broad education necessary to understand the impact of engineering solutions in a global and societal context, and outcomes include the following:

- an ability to function on multi-disciplinary teams
- an ability to identify, formulate, and solve engineering problems
- an understanding of professional and ethical responsibility
- an ability to communicate effectively (Devgan et al, 1997-2).
Plumb and Scott (2002-3) emphasise how crucial writing skills are for engineers, but note the time factor confronting NMMU lecturers as well. Technical modules take up so much time that there is none left to focus on soft skills like accurate writing. Those programs that include writing tend to focus more on writing skills, instead of reflection, critical thinking and understanding the components of the communication process. As confirmed at the NMMU, such processes take time and persistent effort. Scaffolding of teaching and learning has to take place across modules, across the program. Engineering programs struggle with how to prepare students for the writing they will do as professionals. Ostheimer and White (2005) state that engineering professors consistently assert that writing is crucial for their graduates. Estimates indicate that about 80% of an engineer's time goes on communicating. Studies done by the Department of Electrical and Computer Engineering (ECE) at the University of Arizona show that engineering firms and ECE graduates ranked writing ability as the most important skill in determining an engineer's success. Moreover, they ranked writing above the technical skills of the engineering curriculum (Ostheimer and White, 2005).

In the USA, programs have to confirm their educational outcomes for engineering communication to the Accreditation Board for Engineering and Technology (ABET). They have to also prove the process used to evaluate student performance on them. Graduates were not ready to write in the workplace and ABET saw writing as a basic skill for engineers (Devgan et al, 1997-2). The "ability to communicate" and other such goals were included in the criteria because "engineering success today requires more than up-to-the-minute technical capability, it requires the ability to communicate, work in teams, think creatively, learn quickly, and value diversity" (Plumb and Scott, 2002-3).

**The demands made of the modern engineer**

A review of the demands faced by modern engineers exposes the need for the soft skills described above. In the SA context, engineers have to fit into a developing economy, a new democracy, a fractured society. The workplace has colleagues from different backgrounds, with different values and experiences. Diversity may be the flavour of the day, but only if one has the skills to respect and honour diversity, not tolerate it with tight-lipped indifference. Soft skills have to be consciously taught to the engineer, they are not learned by diffusion.

Research on the soft skills displayed by engineering graduates confirms that tertiary institutions are often sending out robots, not the human being we would like. The ability to effectively communicate with others has been lost in our technology driven society. More and more time is being spent interacting with various electronic devices and less time is spent engaged interpersonally. Graduates need to have basic skills to become productive employees and citizens within their community. These soft skills, consisting of effective oral and written communication, leadership and social responsibility, are vital to our success as a nation competing in a global market (University of North Carolina Tomorrow Blog, 2007-1). In the modern workplace, the following service skills were identified as being of critical importance: (Variayar, 2009-2)

- **Project management:** Team work, assertiveness, execution excellence.
- **Knowledge management:** Written English, writing skills.
- **Integrated product teams (IPT), Concurrent engineering:** Spoken English, verbal communication, use of graphical communication methods.
- **Quality systems and processes:** Mindset, attitude, attention to details, assertiveness - including ability to say no when appropriate, Integrity, Honesty, Forthrightness in admitting mistakes.
Global project teams: Business etiquettes, cultural sensitivity, Willingness to seek help.

Rapid changes in business and technology: Stress (self) management, flexibility, adaptability, change management.

Innovation / Productivity improvement: Open, inquisitive mind, creativity.

Variayar (2009-2) affirms the need for training in the above soft skills for the modern workplace, especially because the management of the customer and communication are important. But, he points out that there is a real challenge on sourcing people with relevant soft-skills, and it is becoming necessary to train them on the job in soft skills. He found the problem prevalent in the United States, Mexico, India, China and Poland, noting that at high school, many engineers neglect studying the humanities, languages and arts so they can master science and mathematics, much to the detriment of their soft skill development.

Traditional soft-skills continue to be relevant in the workplace, including...“adaptability, open-mindedness, problem solving, decision making, communication skills, self learning and knowledge discovery, empathy and team work, motivation and attitude encompassing initiative, perseverance in adversity and ability to motivate self and others” (Variayar, 2009-2). With globalization today, technical excellence and newer skills are needed: how to work in a multi-cultural workplace; use of graphic communication, annotations, pictures, creativity and innovation (Variayar, 2009-2).

The NMMU Communications module is attempting to apply what a significant study in Australia confirmed: that engineering educators have a responsibility to society and to engineering. The study, by Male, Bush & Chapman (2009-3), identified 64 generic engineering competencies required by engineers. The results support the expansion of the engineering curriculum so as to develop student competencies beyond the purely technical, as they are not sufficient for success as an engineer. Communication, teamwork, professional attitudes, business skills, problem solving, critical thinking creativity, and practical skills were perceived as highly important. Such competencies are unlikely to be developed through traditional teaching methods. The results imply that non-traditional methods such as problem and project based learning and non-traditional assessment methods are required (Male, Bush & Chapman, 2009-5). Results were consistent with similar comprehensive studies in the USA and Europe. Among others, the competencies rated as critically important by over 50% of their respondents included:

Communication, teamwork, self-management and problem solving;

Communicating clearly and concisely in writing (eg. writing technical documents, instructions);

Managing one’s own communications (eg. keeping up to date, completing a task, following up);

Managing self (eg. time/priorities/ quality of output / motivation/ efficiency/ emotions / work-life balance/ health);

Using effective verbal communication (eg. giving instructions, asking for information, listening);

Working in teams (eg. working in a team / trusting and respecting others/ managing conflict / building team cohesion);

Speaking and writing fluent English;

Interacting with people in diverse disciplines/ professions/ trades;

Practising exemplary ethical standards - integrity;

Presenting a professional image (ie. demeanour and dress, being confident/respectful);
Thinking critically to identify potential possibilities for improvement;
Using effective graphical communication (eg. reading drawings);
Being concerned for the welfare of others in one’s organization - ubuntu;
Participating constructively in meetings (eg. team meetings/ workshops / focus groups / interviews);
Managing personal and professional development (eg. self-directed/ independent learning; learning from advice/ feedback/ experience; thinking reflectively and reflexively);
Doing presentations clearly and engagingly (eg. speaking, lecturing);
Interacting with people from diverse cultures/ backgrounds/ promoting diversity;
Understanding the social and political dimensions of one’s workplace; and
Engaging in active citizenship (eg. being involved in the local /national community).

The Engineering Council of SA (ECSA) has acknowledged the importance of soft skills within the profession, recognising that an engineer is a human being first. Re-curriculation of engineering qualifications now include soft skills as an integral outcome, achieved through the Communication Skills module. However, this module is just one of many modules needed to complete a National Diploma. While every effort is being made at the NMMU to include soft skills in the Communication Skills module, the operational barriers mitigate against long term sustainable teaching and learning.

The Communication Skills Module at NMMU

Recognising the need for graduates to be seen as balanced human beings who also happen to be good engineering technologists, the Communication Skills module is being gradually revised to meet this learning outcome as best it can, within the time frame of a semester of fourteen academic weeks and limited lecture periods. Contact time is currently 2 x 45minute periods per week, with class units ranging from 35 to 120. This is not the most conducive context for optimal learning, but predetermined full time equivalents (FTE) weightings and subsequent budget constraints define lecturer allocation and class size.

Venues used are basic lecture rooms equipped with boards and an overhead projector. Computers and data projectors are used when available, chiefly when presentations are being assessed. Students are given a Tutorial Book containing the lecture content schedule for each week, tasks and activities expected of them and due dates for assignments and tests. Continuous assessment includes two formal tests, a report based on an investigation conducted by students, a presentation of the said report and a Personal Reflections Term Paper, which has to show evidence of some research, reflection, critical thinking, academic writing skills and an ability to take a stand on a specified position. Peer editing the draft encourages writing as a process necessitating time, revision and reflection. Each task carries a weighting of 20%. The pass mark is 50%. A clear question and assessment grid is provided for each task. The outline of the module follows:

NMMU Values and Mission Statement
Communication Theory
Listening Skills
Presentations
Textual Analysis
Writing Skills
Report Writing
Technical Writing

A Term Paper based on the documentary by Al Gore: An Inconvenient Truth

The integration of soft skills into the curriculum

While the outline is of a generic Communication Skills module, it is the hidden curriculum that focuses on the soft skills required to add the human being factor to NMMU students.

The Communication Theory model is taught through the eyes of an engineer, but personalised so as to individually challenge the student. Contexts which are a current reality for students are used as a point of departure, progressing then into the engineering workplace. Self reflection becomes a key practice and learning outcome, based on questions like:

Do I think before I talk? Before I act?
Are my words appropriate? How will my friend feel if I use these words in my text message to him/her?
Is this the right time to call my parent; lecturer; manager?
How will I feel if I am not addressed politely?
Is the tone of my voice polite? Am I too loud; soft; harsh?
Did I read my e-mail carefully before pressing the Send key?
What does my writing style; tone; format; spelling; punctuation say about me?
Am I in the right emotional frame of mind to talk now/ to write a reply?
Is my boy/girlfriend emotionally ready for my message?
Should I delete this message or send it?
Should I walk away now or join the debate?

Manners maketh the man: do I show that I am well mannered; refined; dignified; professional?

The Non-verbal communication lesson offers opportunities to include soft skills like appropriate dress codes; what to wear when; the impact of jewellery, hair style and colours. Students examine their posture and facial expression in different contexts with a diverse audience. Ultimately, the challenge thrown out is whether one’s choices reflect one’s professionalism as an engineer or not.

Barriers to effective communication provide perhaps the best medium to teach soft skills in the SA context. If handled with due sensitivity and respect for the student being exposed to the self, this lesson teaches and challenges one to engage in deep introspection and reflection, a core discipline needed in the shaping of a better human being. It is this introspection that urges one to identify strengths and weaknesses, and to shape one’s self accordingly. Making the lesson interactive by asking students to share their personal experiences and lessons learned adds a much needed dose of reality to the context. The issues of multiculturalism, racism, xenophobia, class, education, poverty and discrimination (HIV-Aids) open the eyes of many students to where they stand on such realities, forcing them to analyse how they will respond to them in society and in the workplace. Discomfort is often visible as the student grapples with his/her personal growth, but students also often linger after such lessons to share more detail, or to continue talking about other experiences. From the lofty heights of introspection, barriers include some very basic social skills that are taught through the writing
lessons: how to avoid body odour and halitosis; respecting the personal space of others. The professional engineer is but a human being!

**Listening theory** complements what the student learns in verbal communication. Many find it difficult to accept that one has to train one’s self to listen, that it is hard to zip up one’s mouth. A minister once preached that in order to improve our soft skills, we should all pray for the blessing of **Shut Up**! Asking students if they have friends who talk non-stop draws much laughter as they generally agree, followed by some uncomfortable faces when asked if they dominate conversations with friends. It is this kind of personal reflection that seems to be achieving the identified soft skill outcomes which will, hopefully over time, become internalised character traits of the student. In turn, it should lead to graduates who would be a better fit in the engineering workplace.

The **two tests** written by engineering students offer a perfect opportunity to teach the hidden curriculum, enabling the integration of soft skills education while assessing academic content. Topics covered have included letters by persons suffering from HIV-Aids; the debate on multilingualism in SA; voter education through advert analysis and letters to the editor; the need to make the right choices in all one does; local history; the value of having insurance; financial management; healthy relationships; global warming; sexism; energy saving and skills needed on becoming a parent.

A similar line of teaching is integrated into the different aspects of the Communication Skills Module: where reflection on one’s growth as a person is the focus through reading relevant texts; editing one’s **writing**; evaluating peers as they do **presentations**; working closely with a friend on a **report** project and finally, merging evidence of all stated outcomes in the **writing** of The **Term Paper**. This is a research assignment recording the student’s personal experiences/ standpoint/ thoughts on global warming and how it impacts on the work of an engineer, together with how and why these thoughts were shaped by other persons/ researchers/ practising engineers. Critical thinking, personal reflection, evaluation of content, research skills, referencing and ability to write a paper (within the parameters of the question and instructions) are overtly **academic skills**. However, inherent in the academic process are **soft skills** necessary for success as a person: discipline, perseverance, determination, ethics, moral courage, enthusiasm, pride, motivation, confidence and belief in one’s self. The final product, in all its glory as per the student’s standards, is a good indication of one’s maturity as an engineering student, and as a human-being-in-progress. The key seems to lie in informing the student of the academic skills gained from writing The **Term Paper**, as well as the soft skills inherent in the exercise. Once students are aware that completing the task indicates that they have confidence, motivation and determination, they seem more willing to do it, subconsciously identifying themselves as having the values discussed.

**Justification for the integration of soft skills into the curriculum**

The NMMU’s Vision 2020 seeks to send out graduates who exemplify six core values: ubuntu, integrity, respect for the environment, excellence, diversity and responsibility. Translated into best practice, this means a three year academic and student experience that teaches, nurtures and visibly promotes these values so that they become internalised by the student. The education situation is the everyday experience, both academic and informal. The facilitator for such experiences, specifically for the engineering student, is every lecturer who teaches him/her. It is therefore incumbent upon every lecturer to seek and find ways to show evidence of these values within one’s module content, delivery mode, assessment methods and especially in how one interacts with the student. It is the lecturer’s responsibility to prepare the student for employers, for society and for family.
“...most of SA’s first-year university students could not read, write or comprehend nor could they spell” (Eloff, 2009-1). In a study done in 2002 on the preparedness of engineering graduates in SA, employers indicated that graduates lack the ability to communicate information through written reports/business letter writing (De Jager & Nieuwenhuis, 2002-67). After a long process of consultation with relevant stakeholders, ECSA recently published revised outcomes-based standards for the professional registration of Engineers, Engineering Technologists and Engineering Technicians. These generic standards clearly specify the required exit level outcomes for each of the professional pathways. An example of such a relevant learning outcome follows: the particular engineering learner completing this qualification will be competent and able to demonstrate the following learning outcome, namely communicating technical information in a professional manner (ESGB for BEngTech, 2009-3).

For the Communication Skills module, the integration of the soft skills described earlier include academic activities focussed on critical thinking, reading, writing, verbal and non-verbal practice. Each of them has sound pedagogic foundations, and their practise is supported by ECSA. In the Figure 1 below, Simpson and van Ryneveld, (2009-14) summarise the extent to which reading, writing and critical thinking abilities are required in the ECSA Exit Level Outcomes for the B(Eng) programme. Literacy practices form almost two-thirds of required assessment criteria for graduates. These practices are further tested upon professional registration with ECSA.

Figure 1. Percentage of ECSA ELO assessment criteria mentioning/requiring broad literacy practices

According to ECSA (2003: 8-9) and as pointed out in (Simpson and van Ryneveld, 2009-3), the professional review that they conduct allows engineers to demonstrate that they:

- understand the professional environment of Engineering, including moral, ethical, environmental and safety issues;
- have developed skill in engineering judgement, can make responsible decisions, can communicate lucidly and accurately, identify problems and find solutions to these, and that they can implement these solutions, and
- have adequate technical knowledge and understanding.

To become professional engineers, ECSA has very specific communication requirements for sub-disciplines. Candidate engineers “must develop the ability to communicate lucidly, accurately and with confidence” (Simpson and van Ryneveld, 2009-9). In Industrial and Civil Engineering, a formal presentation is required. Candidate civil engineers have to write two
essays on a technical engineering aspect and on the ‘engineer in society’ and management concerns. Language skills include sentence construction, use of verbs and tenses, concord, spelling, punctuation, use of jargon, use of acronyms and use of abbreviations. However, Simpson and van Ryneveld (2009-9) warn that “language competence is of little value if candidate engineers are unable to engage in the higher-order reading, writing and critical thinking processes.”

In essence, the Personal Reflections Term Paper based on An Inconvenient Truth touches on aspects of the above skills, albeit at first year level. The technical report and writing add depth, as does the formal presentation, but note, this is not enough. Each innovation introduced was carefully considered to apply Vygotsky’s (1987) constructivist theory, moving from what the student knows to what one needs to know as an engineer-in-progress, a human-being-in-progress. Vygotsky's premise is that students write to learn, and that this learning stretches across the curriculum. A variety of learning tasks is expected of the student, implying teaching within Vygotsky's zone of proximal development - accomplished jointly by lecturer and student to make the most of teaching and learning in the engineering education situation. The student needs to be led into this zone of proximal learning and development. On leaving the Communications class, it is the responsibility of engineering lecturers to scaffold on this foundation, providing students with the opportunities and tools needed for teaching and learning to be further assimilated. Simpson and van Ryneveld (2009-4) confirm that “…it is the role of Engineering educators not to merely transmit knowledge but to provide students with the tools, including the literacy tools, needed to engage in ‘being’ an engineer.”

In their writing of the Term Paper, students are not to merely regurgitate facts, neither are they required to write a review of the documentary. They do need to reflect on, reason and argue, all based on evidence from the documentary, further reading and interviews they conducted. They are encouraged to take a stand on the issue of climate change, be bold in how they express their point of view, provide details of the criteria on which they based their conclusions and show referencing within their essay text. In the complexity of the modern workplace, such skills will benefit the practising engineer because they enable assimilation and consolidation of learning. “Writing involves exploring one’s thoughts and learning ... it is not simply the mechanistic skill of reproducing ideas” (Zamel,1987-267). Writing is thus a key means by which the development of reflection and independent learning can take place. Leibowitz (2000-20) confirms that reflection is a key aspect of writing.

Evaluation of the Communications Module

While the effort to integrate soft skills into the Communication Skills Module is clearly evident, do they actually make a sustainable impact on the student’s life? For the short term, maybe; for the long term, one cannot be certain because of the many barriers faced by the module itself. The engineering diploma structure determines its contact time, FTEs, credit weighting (0.042), semester schedule and class unit numbers.

The module is offered at entry level, in the first semester of a student’s enrolment. Emotionally and psychologically, they are not even remotely thinking about how to apply the soft skills being taught for the workplace, which seems to be too far away in the future. At the end of three years, the skills may very well be forgotten.

Recommendation: The Communications Module should be offered in the second or preferably, third year of study if it is to prepare students for the following year in the workplace.
The module at NMMU extends over just fourteen academic weeks, with three periods per week allocated to it. That is 2 ¼ hours per week. However, the FTEs allocated for the module translate into less than one hour per week. For the benefit of the student and to do some justice to the module, lecturers are currently teaching 2 ¼ hrs per week = 21 hours per semester. There are three full-time staff members who are teaching engineering (yet 38,683 FTEs = ½ a teacher). Besides this, the module has a credit weighting of 0,042 (meaning 5 hours per semester). To clarify, if notional hours for credit weightings are considered and applied by the rule, then engineering students qualify to get five hours per semester of communication skills, soft skills and preparation for the work place. This alone indicates the low level of importance allocated to the module by the engineering powers that be.

Recommendation: Four periods a week will be acceptable over one semester. The module will be more effective if offered over a year. FTEs should be increased to justify this time allocation. Credit weighting should be increased.

Once over, no other module studied by the student covers any aspect of soft skills. Their time table is extremely crowded, many take more than the three years to qualify and at the end of their study, they enter the workplace as unprepared graduates. The points raised in this paper expose their inability to fit into the modern world.

Recommendation: Every module should have a section devoted to people relationships in the workplace. Soft skills should form an integral part of this section. Engineering lecturers should be encouraged to actively research what needs to be included here, and why.

Students do not see any connection between the Communication Skills module and their engineering discipline. Indeed, Simpson and van Ryneveld, (2009-13) go further when they argue that the tendency to restrict curricula to modularized, specialized courses is a negative one. Students need to understand that the decisions engineers make impact on the social; they have an ethical and legal responsibility towards society. Compartmentalising engineering courses does not “allow students the opportunity to develop the higher-level skill of synthesis – taking information from multiple sources and putting them together to form a coherent whole. Compartmentalisation ignores the interconnection of different subject areas and disciplines” (Simpson and van Ryneveld, 2009-13).

Recommendation: The holistic interconnection of the different modules making up the engineering qualification should be consistently explained to students.

The attitude to the Communication Skills Module by engineering lecturers and students is a very visible barrier. Many see it as an unnecessary elective which they don’t need to take seriously, so they avoid attending class, do not submit assignments and sometimes just turn up to write the final test. It does come as a shock to many when they fail the module, and even more so when they realise that they forgot to redo it just when they were planning for their graduation.

Recommendation: Lecturers and students need to recognise their role as human beings in society first, then as engineers in that same society. Students are currently given only fourteen weeks to learn a few basics about being better human beings. Lecturers should therefore promote the module in a more positive light.

The integration of soft skills into the Communication Module means that the readiness level of the student necessarily has to be higher. More maturity is needed; the ability to reflect is critical; the ability to engage in the process of writing enables learning; time management skills are essential, as are knowledge of world events, personal responsibility and an
understanding of the modern workplace. Fitting into a multicultural society demands understanding of South Africa’s past, present and future. At first year level, the student is not ready to intrinsically assimilate the needed soft skills taught.

**Recommendation:** The Communications Module should be taught over two semesters in the second or third year of study so that students can better internalise the soft skills taught.

**Whose responsibility is it to teach soft skills?**

“Professional engineering is not just a job – it is a mindset and *sometimes* a way of life” (Engineering Council UK, 2003-3).

Variyar (2009-3) recommends that in changing times, “soft skills are best combined with communication skills integrated with understanding the psychology of the student and the content being taught.”

The Communications Lecturer can only do so much over fourteen weeks at first year level. By default thereafter, every engineering lecturer has the responsibility to reinforce and continue what has been started. With this responsibility comes ethical and moral obligation: if they do not educate engineering students into becoming better human beings who also happen to be good engineers, then whose responsibility is it? Sending out dysfunctional graduates will unfortunately, and often unfairly, be seen as a reflection of the lecturers who taught them, lecturers who should have touched and shaped their lives. It is therefore, the responsibility of every engineering lecturer to recognise that he/she is choosing to be a teacher first. As such, it is the lecturer’s responsibility to actively teach soft skills within the content of their respective modules.

Professional teaching is not just a job – it is a mindset and *always* a way of life. Indeed, it is a calling of the highest order.

**References**


ICCSE Invited Lecture: Importance of Development of Soft Skills in Engineering  
University of North Carolina Tomorrow Blog, Wednesday, August 1, 2007. Soft skills – who really needs them? And wait, what exactly are they?  
Community-Based Outreach as a Component for Engineering Education

Martina Jordaan
Department of Infomatics, University of Pretoria
martina@up.ac.za

Abstract

The post-apartheid higher education sector in South African higher made higher education more assessable to all South African citizens. This has put a greater burden on higher education institutions to take be accountable for the community at large. By including a community-based learning module in the undergraduate engineering curriculum, the importance is placed on hands-on task-orientated projects that assist students to obtain and apply knowledge that is useful in understanding their immediate social context, build critical thinking capabilities that will contribute to essential questions about learning and society, and thereby develop a commitment and responsibility to both. Through community engagement programmes, students may be involved in undertakings that address local needs, while increasing their academic skills and commitment to their communities. Students also develop a sense of responsibility towards society and learn cultural tolerance. Higher education institutions are also beginning to move away from the concept of outreach and focus more on partnership models. Community engagement can be used to strengthen and expand on teaching and learning in higher education institutions. Linking discovery and learning to the real needs of a local and worldwide community stimulates the work of both faculty members and students. The paper reflects on the implementation of community outreach modules in higher educations and review the possible outcomes of the implementation of such a module via the feedback from students and a case study.

Background

The changing face of the South African higher education sector in the post-apartheid era made higher education more assessable to all South African citizens. This has put more pressure on higher education institutions to take responsibility for the community at large. Higher education institutions could no longer function in isolation, but had to be relevant and incorporate community engagement into their mission statement and vision.

Calls for more community involvement have led higher education institutions to face their social responsibilities of making their students aware of the broader needs of communities and allowing them to share their acquired knowledge with communities.

A knowledge gap exists between current engineering graduates’ attributes and skills and expectations from government and the private sector. One of the core skills that is still aligned with the needs of government and the private sector is that students must be able to be proactively task-orientated and able to apply knowledge independently within a specific social context. It remains important that learning is linked to the acquisition of general social intellectual skills, attitudes and values.

By including a community-based learning module in the undergraduate engineering curriculum, emphasis is placed on proactive task-orientated projects that assist students to acquire and apply knowledge that is beneficial in understanding their immediate social context, build critical thinking capabilities that will contribute to fundamental questions about learning and society, and thereby develop a commitment and responsibility to both.
Community-based learning involves students making a positive contribution to individuals in a specific community and develops a combination of knowledge, skills, values and motivation to make a difference, thereby promoting the quality of life in a community.

This paper will discuss the importance of adding community outreach initiatives to the curriculum of engineers and how students perceive their involvement in community projects as relevant to their future careers. The importance of community outreach initiatives must be viewed against the historical and political background of South Africa.

**Higher education in post-apartheid South Africa**

Higher education institutions in the post-apartheid era are expected to produce graduates who will contribute to South Africa’s economic growth and promote democracy in society through their roles as educated and self-assessing citizens. The internationalisation of higher education institutions and the emergence of a large array of new researchers and innovators mean that, in order to remain competitive, higher education institutions must display far greater levels of socioeconomic responsiveness and continuously improve the quality of their academic programmes (Strumpf, 2001:223).

In February 1995, the National Commission of Higher Education was founded and given until the end of 1996 to produce proposals for the comprehensive restructuring of the higher education system in South Africa. The Commission had to develop a strategy with sufficient popular legitimacy to transcend the existing educational dichotomies and lay the groundwork for a higher education system that would foster cooperative interdependence (Moja, 1996:52).

The National Commission on Higher Education produced a report in 1996, which was followed by Education White Paper 3 in July 1997, in which the government issued a policy document laying out a set of goals regarding the size, structure, governance, funding and other aspects of post-apartheid higher education institutions in South Africa. The document, entitled *Education White Paper 3: A Programme for the Transformation of Higher Education*, stipulated that “higher education plays a central role in the social, cultural and economic development of modern societies and that the challenge in South Africa is to redress past inequalities and to transform the higher education system to serve a new social order, to meet pressing national needs, and to respond to new realities and opportunities” (South Africa, 1997:8–9).

The White Paper also states that one of the goals of the revised higher education system is to promote and develop social responsibility and awareness among students, as well as to promote social and economic development through community service programmes (South Africa, 1997:10). It makes frequent reference to the need for new partnerships. In a section called *Join hands to build the new education and training system*, the White Paper on Education and Training (South Africa, 1995:n.p.) states that the Ministry of Education invites the goodwill and active participation of parents, students, community leaders, religious bodies, non-governmental organisations, academic institutions, workers, business, the media and development agencies to design a new education and training system. The White Paper does not elaborate on what type of partnership is intended, but partnership of some kind is clearly the favoured mechanism of forging a new relationship between government and civil society (Moja, 1996:142).

Along with other core focuses, such as research and teaching, the notions of service learning, social responsibility and community engagement have now become important for universities in the South African higher education sector. These activities are seen as being vital and
directly related to the social and economic development of the country. Knowledge-based community service has also become a requirement for quality assurance and programme accreditation (Council on Higher Education, 2009:81).

Since the mid-1980s, discourse and practice regarding community involvement by higher education institutions have shifted from the notion of outreach to community engagement. Community engagement implies a less paternalistic and more mutual and inclusive partnership between communities and higher education institutions (Council on Higher Education, 2004:130).

Higher education institutions in South Africa have also expanded the orientation of their community service in order to prepare and develop academics for the needs of effective service delivery in higher education. The Higher Education Act, Act No 101 of 1997, emphatically accentuates the need for higher education institutions to produce academics that not only pursue learning and research, but also respond to the human resources, economic and societal developmental needs of the South African community (Waghef, 1999:109,112).

Prior to the White Paper of 1997, there were no policy mandates or directives for community engagement in the South African higher education sector. Since 1997, initiatives by the Joint Education Trust have been the major force in supporting the development of a feasible study that explores the potential of community service in higher education (Council on Higher Education, 2004:132,135). During 1997 and 1998, the Joint Education Trust conducted a survey of community service in the South African higher education sector, and in 1999, the Trust launched its Community Higher Education Service Partnership Project, which was published in two monographs. The steering and research committees for the survey included a number of senior officials from the Department of Education, including the Minister of Education.

The survey sought to develop some understanding of community engagement and its potential role in the South Africa higher education sector, as well as to stimulate informed debate around this issue. The survey included studies of historically advantaged and historically disadvantaged universities and technikons in both urban and rural settings. It also analysed programmes in terms of their goals, design, scale, supporters and beneficiaries, cost and financing, partners and institutional support, and relationships between the programme and the curriculum (Council on Higher Education, 2004:132).

The purpose of the Community Higher Education Service Partnership Project was to support the conceptualisation, implementation, monitoring, evaluation and research of a pilot service learning initiative. Thereafter, the data that was generated through this process was used to update higher education policies and practices at a national, institutional and programmatic level. The initiative was launched with the development of a graduate programme, Community Higher Education Service Partnerships, which was registered through the Leadership Centre at the former University of Natal. A number of higher education institutions assisted in conducting an institution-wide audit of community engagement and developing an institution-wide policy on the issue. Developing a strategy for the implementation of this policy, and conceptualising and implementing a range of accredited academic courses that incorporated the principles of service learning across a variety of disciplines were among the main goals of the project (Council on Higher Education, 2004:135).

The goal of the Community Higher Education Service Partnership Project was to contribute to the reconstruction of South African society through the development of a socially
accountable model for higher education. Among the key findings was that although most higher education institutions had a wide range of community service projects and their mission statements included the notion of community service, none of the institutions had a policy to operationalise the community service component of their mission statements.

Rather than being a deliberate institutional strategy, the community service projects were usually initiated by students and academics who were attempting to address specific community needs. The projects did not embrace the three functions of higher education, namely teaching, research and service. Most of these projects did not include any form of partnership model in their conceptualisation or implementation either. Where projects included teaching, research and service, and where partnerships had developed between participating constituencies, the benefits to communities, academics, students and the service agencies were significant (Council on Higher Education, 2004:132–133).

The Joint Education Trust identified five types of community service programmes, namely volunteer programmes, work-study programmes, community outreach programmes, extension service programmes and placements or cooperative education programmes (Council on Higher Education, 2004:133). It proposed the development of partnerships between communities, higher education institutions and the service sector in order to address national development priorities (Mohamed, 2006:1).

The Green Paper of 1998 on national youth services, developed by the National Youth Commission, called for community service programmes to be integrated into mainstream academic programmes in higher education institutions. In 1999, the Southern African Student Volunteers released a position paper calling for mandatory community service in higher education institutions. The South African Qualifications Authority formed a task group and commissioned a discussion document on community service. The aim was to stimulate debate and action within a framework of key conceptual and implantation issues.

In July 2000, the Council on Higher Education, which was set up in May 1998 to provide advice to the Minister of Education on higher education policies, issued a report, entitled *Towards a New Higher Education Landscape*, that revisited many of the issues arising from the 1997 policy document. The proposed new national framework that would reconfigure the South African higher education system “in a principled and imaginative way, more suited to the needs of a democracy and all its citizens, in contrast to the irrational and exclusionary imperatives that shaped large parts of the current system” (Council on Higher Education, 2000:5).

In February 2001, the South African Cabinet approved the National Plan for Higher Education, which was intended to implement the goals set out in the 1997 legislation and highlight the inefficiencies that plagued the higher educational system at the time. Confirming the policy shift away from access and equity, and towards efficiency, the plan asserted that the main focus would be on improving the efficiency of the higher education system through increasing graduate outputs (South Africa, 1997:30).

The founding document of the Higher Education Quality Committee (2001), part of the Council on Higher Education, identified knowledge-based community service as one of the three areas (along with teaching and learning, and research) for programme accreditation and quality assurance in higher education. The Higher Education Quality Committee designated community engagement as the service learning component of its national quality assurance system. In June 2004, the Higher Education Quality Committee released its Criteria for
Programme Accreditation, which identified the minimum requirements for service learning in higher education institutions.

During 2003, a collaborative effort between the Higher Education Quality Committee, various higher education institutions and the Joint Education Trust generated a comprehensive list of criteria for the quality assurance of service learning at both institutional and programme levels. The policy, which was in draft form in mid-2004, was based on research data that was generated from more than 200 accredited pilot service courses and interviews with numerous higher education stakeholders, including university vice-chancellors, Department of Education officials and student bodies. Higher education institutions were required to formalise quality-related arrangements for community engagement programmes, integrate them into teaching and learning, and adequately monitor and support the projects (Council on Higher Education, 2004:134).

An independent review of the results of the Community Higher Education Service Partnership Project indicated that while courses that were developed and implemented as a result of the intervention benefited the students, lecturers and communities, course coordinators experienced a lack of support from senior management and struggled with a lack of resources.

The institutionalisation of community outreach was uneven. Most outreach projects were not sustained by higher education institutions beyond the financial support received from the Higher Education Service Partnership Project. This resulted in a strongly negative outcome for the community outreach programmes at some higher education institutions. Even though the Higher Education Service Partnership Project assisted higher education institutions in providing community engagement programmes with financial aid, the intended increase in outreach programmes through extensive institutionalisation did not occur.

Between 2004 and 2005, higher education structures were reassessed, and the intervention known as “size and shape” resulted in a consolidated sector that was reduced from 36 to 23 institutions through mergers and campus incorporations that affected most institutions. Universities offer a mix of programmes, including career-oriented degrees, professional programmes, formative programmes, research master’s programmes and doctoral programmes (Council on Higher Education, 2009:8).

The importance of community engagement in higher education

Higher education institutions continue to grapple with the meaning of social responsibility and community engagement, even though they continue to implement a variety of programmes under this banner. A great variety of practices have manifested themselves at higher education institutions, ranging from student volunteerism, service learning, engagement with policy-makers and community-based action research to offering specialist skills and other consulting work to communities (Council on Higher Education, 2009:81).

The focus is on understanding and analysing the social responsibility or community engagement practices within a university. Many people are of the opinion that higher education institutions can make a unique contribution to society and provide a powerful knowledge base to help tackle societal problems (Council on Higher Education, 2009:83).

The decrease in state funding and the notion of accountability for public funds has moved higher education institutions closer to other participants in communities and has brought about the establishment of partnerships (Asmal, 2000:n.p.). Education initiatives are one of
the most effective means of creating and shaping new relationships among all stakeholders in society (Donnay, 2001:6).

In the process of initiating community partnership projects, it is important for all parties to be recognised as equals and for both communities and universities to contribute to the intervention. A successful partnership between higher education institutions and communities is based on a shared philosophy, vision and values. Mutual accountability and responsibility, communication, evaluation, equality, sustainability, reciprocity and feedback should be high priorities for all concerned parties (Council on Higher Education, 2009:84).

The most successful initiatives are linked to teaching and learning or research programmes. Community engagements need to be integrated into the pre-existing activities of higher education institutions (Council on Higher Education, 2009:84).

Higher education institutions are key players in domesticating knowledge and diffusing it into the economy. They need to serve as engines of both community development and social renewal. The developmental role higher education institutions play must be to be put to use in the service of the community (Juma, 2005:n.p.).

Most political and professional leaders are products of higher education institutions. This places higher education institutions in a strong position to help reshape the culture of a country. The undergraduate social experience has a significant effect on people’s political beliefs and other values. The outcomes, such as maturity of moral judgment, racial and religious tolerance and civic and political participation, are directly linked with attaining education. Higher education institutions must, therefore, move away from being merely a database of facts, and strive to provide students with the competence to act in the world and the judgment to do so wisely (Ehrlich, 2000:xxviii).

Community engagement can be used to strengthen and expand on teaching and learning in higher education institutions. Linking discovery and learning to the real needs of a local and worldwide community invigorates the work of both faculty members and students. It reconnects colleges and universities to expertise and resources outside the campus gates. Community engagement is a renewal of the civic mission of higher education institutions and is a bold course for academic practice (Brukardt, Holland, Percy & Zimpher, 2004:1).

Community-based projects enhance the personal growth of students, particularly with regard to their self-esteem and social responsibility (Stukas, Clary & Snyder, 1999:2). It exposes students to the challenge of working with people from different backgrounds, cultures, and ages; it prompts them to work under time constraints and to be aware of life issues; and it leads them to address problems, the solutions of which are beyond their reach. It also connects students to their local communities, forging bonds between them, their schools and community organisations.

Therefore, community engagement is important in shaping students and future citizens and in producing knowledge that is relevant and useful in the South African context (Lazarus, 2001:5). Through community engagement programmes, students are involved in activities that address local needs, while developing their academic skills and commitment to their communities (Garcia & Robison, 2007:1). Students also develop a sense of responsibility towards society and learn cultural tolerance (Council on Higher Education, 2009:81). Higher education institutions are beginning to move away from the concept of outreach and focus more on partnership models (Langworthy & Turner, 2003:n.p.).
The recorded benefits are mainly to the teaching programmes that include opportunities for interaction between diverse groups of people, thereby promoting social awareness and critical citizenship among students, enhancing student learning, providing richer and more relevant curricula and facilitating a greater transfer of skills and knowledge. Research has benefited from access to research sites, opportunities to collaborate across disciplines and improved focus and relevance. Communities that have been the focus of engagement activities have benefited from interventions that provide food and services that range from training and advocacy to access to expertise (Council on Higher Education, 2009:83).

**Why community outreach must be a component for undergraduate engineering courses.**

One of the central questions at higher education institutions is what students are to learn. It is also important that students be encouraged to think for themselves. Students in higher education institutions are not learning as effectively as they should. More importance in terms of learning is also attached to the acquisition of general intellectual skills, attitudes and values (Ramsden, 1992:17, 19). Learning has to occur as part of the activity or experience in which it occurs.

The aim of community-based learning is to connect the personal and intellectual, and therefore to help students acquire knowledge that is useful in understanding the world, build critical thinking capacities that will lead to fundamental questions about learning and society, and thereby develop a commitment and responsibility to both (Eyler & Giles, 1999:14), and develop a combination of knowledge, skills, values and motivation to make a difference, thereby promoting the quality of life in a community (O’Connor, 2006:52). These skills are important building blocks for future engineers to be accomplished employers and employees.

Higher education institutions acknowledge that one of the major benefits in qualifying from such an institution is the ability of graduates to walk into any position in industry and to be a productive member of the company from the start of their employment.

In 1998, the Engineering Council of South Africa adopted an outcomes-based framework of accreditation. With the exit level outcomes, neither the content nor the structure of a programme is prescribed. Engineering programmes develop their own curricula to satisfy these generic exit level outcomes. This allows more freedom for programmes to define their own content as the emphasis has shifted from what students know to how students can use what they know (Case & Collier-Reed, 2010:11).

Community-based learning shows students that each of them can make a difference. It increases their confidence as citizens. All the students’ collective actions are not always successful, but it teaches students how to learn from mistakes by engaging in a continuous sequence of action and reflection (Mendel-Reyes, 1998:37–38).

**Current community-outreach modules in undergraduate courses for engineers in South Africa?**

The inclusion of a compulsory community outreach module in the curriculum of undergraduate engineers is not compulsory in South Africa and many students get involved in community outreach projects via voluntary outreach projects on campus, seminars and workshops.

During the past few years, engineering faculties in higher education institutions in South Africa have started to include a community-outreach module in the undergraduate curriculum. This has varied from including a philosophy module to the curriculum that includes an outreach endeavour to schools, concentrating on mathematics assistance with
reflection assignments afterwards, as in the case of the University of Stellenbosch (University of Stellenbosch, 2008: n.p.), creating a separate module where students assess their community outreach and reflect on it, as in the case of the University of Pretoria (Jordaan, 2010:18), and delivering presentations and seminars, as in the case of the Central University of Technology, Free State (Central University of Technology, Free State: n.d.).

Case study of a community engagement module

The Faculty of Engineering, Built Environment and Information Technology (EBIT) at the University of Pretoria implemented a new compulsory module, Community-based Project, for all undergraduates from 2005. This module was a first for EBIT students in South Africa. One of the prerequisites of the module was that it had to be designed and developed to take the demanding schedules of these students into account.

The module is offered on an open-ended and project-orientated basis. Students are required to submit topics, in the form of a proposal, for evaluation and approval and have to attend compulsory orientation sessions before they can start with their projects.

Students have the option to attempt the 8-credit (80 hours) module in any one of their undergraduate years of study and must register for the module in the year of their choice, but preferably not during the final year of their undergraduate studies. Depending on the specific nature of the project, it can be attempted during the course of a semester, during vacation time or both (Jordaan, 2010:18).

Projects can be executed by individual students or in teams. The condition for team projects is that a distinct task be allocated to each of the team members and that each of the team members be assessed individually. Multidisciplinary project teams are encouraged, meaning that project teams consisting of team members from across the various schools and departments within the faculty will be encouraged.

This module was a new endeavour of the faculty. The community-based learning is not included in existing modules and was established as a new, separate module. The main reasoning behind this was that most of the students enrolled for this module are second-year students and not yet qualified to do projects related to their field of study.

Students choose projects in an area they feel passionate about. They also have to determine the community’s needs before they can start their project. Projects that are popular among students and the communities are computer training for community members, designing and uploading websites for non-profit organisations, assisting secondary school learners with Mathematics and Science, renovating rooms in orphanages, and designing and building jungle gyms.

The objectives for the inclusion of a community outreach module in the curriculum of undergraduate engineering students included the execution of a community service-related project aimed at achieving a beneficial impact on a chosen section of society, preferably but not exclusively, by engagement with a section of society that is different from the student’s own social background. The development of an awareness of personal, social and cultural values, an attitude of being of service, a deep understanding of social issues, and important multidisciplinary and life skills, such as communication, interpersonal and leadership skills, is important (Jordaan, 2010:18–20).

The learning outcomes for such a module, depending on the nature of the project chosen by the student, demonstrate that learning outcomes relevant to the project have been achieved. This includes the ability to develop a deep and broad understanding of the social issues
relevant to the project, the ability to communicate effectively with the community at large, the ability to communicate effectively through writing and presentations, the ability of performing leadership functions, and the ability to work effectively in a multidisciplinary environment and perform critical functions (Pienaar, 2004:n.p). By doing their community outreach projects, the students get the opportunity to apply their acquired knowledge with regard to basic project management, including logistics, budgeting and completion of project to the satisfaction of the community.

Formal and informal feedback that students provide can be viewed as an indicator if the outcomes of the module have been achieved.

Feedback of the students

In order to assess the outcomes of the module, data is annually collected via opinion polls on the University’s Learning Management System (LMS).

As part of their assignments, students have to indicate in an opinion poll assignment how they feel towards their outreach projects before and after completion of the projects. Figure 1 provides an overview of the students’ willingness to participate in community outreach projects. Students have to complete this opinion poll before they identified and do their project. Because of the challenges that students experience, such as hectic time schedules, students initially do not see the need for such a module in their curriculum. Their attitude towards the module’s outcomes do change after the completion of their projects. Students may also have not viewed the completion of the poll assignment in the LMS as important.

The weighed of the opinion poll assignment contributes only 6% the total mark of the module.

Figure 2 indicates the students’ responses to the question if, in their option, they expect to gain knowledge and skills that will be valuable for their career. Figure 3 reflects the responses of the students after the completion of their projects and their experiences thereof. The high number of students that did not respond each year can be attributed to the fact that these assignments are conditionally opened online on the LMS after students have read the guidelines of the module and have indicated that they understand what is expected of them in order to complete the module successfully.

Without taking the negative response into account, the highest percentage of students indicated that they realised that they had a social responsibility to the community. This assignment was completed before the students started their fieldwork. The aim of the question in the opinion poll is to establish what percentage of the students may view their involvement in the communities as meaningful for their future career. The highest percentage of students indicated that they were of the opinion that the outreach endeavour would be valuable for their career. It is important that students already develop a vision of what they want to achieve in their future working environment and some students already experienced some exposure of their working environment during vacation work. This correlates with Eyler & Giles (1999:170), who indicated that community-based projects resulted in a deeper understanding and application of course content. In their study, the students indicated that their community service made subject matter come to life.
Numbers indicate percentages

**Figure 1.** Solving problems in the community

**Figure 2.** Skills and experiences gain from the module

**Figure 3.** Feedback from the students on their community outreach experience
The experience of the highest percentage of students of their community outreach was either very satisfied or somewhat satisfied. This correlates with Billig (2007:24), who indicated that when community engagement projects were viewed as valuable, useful, relevant or interesting, students become more engaged and acquired a greater level of knowledge and skills. The students overall positive experience with the outcome of their fieldwork can therefore be linked to their initial opinions as illustrated in Figures 1 and 2.

Community engagement also becomes more meaningful for students when they choose the issue to address, when the issue requires analysis and problem-solving and when there is a personal connection with the community to the task at hand. Community engagement only becomes meaningful for students when the service actually meets an important need of the community. Research has shown that projects must be of sufficient duration – typically at least a semester or 70 hours – to have an impact on students (Billig, 2007:25, 26).

Community outreach initiatives’ impact on the skills and attitudes of students

Community-based learning shows students that each of them can make a difference. It increases their confidence as citizens. All the students’ collective actions are not always successful, but it teaches students how to learn from their mistakes by engaging in a continuous sequence of action and reflection.

As they implement service projects, students usually develop greater awareness of social issues and the need for civic responsibility. They often learn leadership, teamwork and social skills, and improve their critical-thinking and analytical abilities. In the process, they tend to increase their self-confidence and self-efficacy.

Feedback from students is encouraging and their positive attitude reflects in their reflections on their projects. Positive qualitative feedback from students includes the following personal comments:

I felt good about my project as the hours were flexible and the work was rewarding.

The benefits which come with such a project are endless. The children are able to enjoy a safe playground and we as students got to experience new surroundings and underprivileged people and we created bonds between the people and ourselves for future opportunities.

I have benefited a lot as I have learned to be patient with people because people don’t have the same mental ability. The students have benefited as well because their reasoning ability is not the same as it was before and they have learned new techniques on how to approach problems. Their self-esteem develops in their positive attitude towards their subject.

In assessing a student’s project work, the mark allocation is based on what the student has learned during their involvement in the implementation of their community projects and on the extent to which the above learning outcomes have been achieved. Thus, the student’s grade is awarded specifically for the quality of learning exhibited, and not for the quality or quantity of the service provided.

Conclusion

Calls for more community involvement have led higher education institutions to face their social responsibility and to make their students aware of the broader needs of communities, and allow them to share their acquired knowledge with communities. This has become one of the central goals of higher education institutions. For students, community-based learning provides opportunities for meaningful involvement with the community. As students implement community projects, they usually develop greater awareness of social issues and
the need for civic responsibility. They learn leadership, teamwork and social skills. During their involvement in their community projects, they improve their critical-thinking and analytical abilities and, in the process, they tend to increase their self-confidence and self-efficacy. Community-based modules, especially those with strong social justice designs, such as the compulsory Community-based Project module implemented within the Faculty of Engineering, Built Environment and Information Technology (EBIT) at the University of Pretoria, have a positive influence on students’ development of social responsibility. Feedback from students received over the last few years verifies the positive impact of the Community-based Project module.

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Towards Collaborative Practices of Academic Citizenship in Mechanical Engineering Education at a Comprehensive University: A Critique of Discourses

Anne Knott¹, Hannalie Lombard² and Pat McGrath²

¹Centre for Teaching Learning and Media, Nelson Mandela Metropolitan University, South Africa; ²Department of Mechanical Engineering, Nelson Mandela Metropolitan University, South Africa

¹Anne.Knott@nmmu.ac.za, ²Hannalie.Lombard@nmmu.ac.za, ²Pat.McGrath@nmmu.ac.za

Abstract

Within a collaborative teaching, learning and research project on a campus of a merged comprehensive university, the authors of this article practice ‘academic citizenship’ across disciplinary and structural boundaries. The project, which began in 2010, aims to make explicit teaching and learning through language and literacies in relation to socially-situated genres, such as laboratory reports, which students are required to write in modules as part of the National Diploma in Mechanical Engineering programme pegged at level 6 on the current National Qualifications Framework. We describe, explain and theorise our social practices at different phases. In addition, our methodology of discourse analysis identifies, analyses and critiques a dominant traditional discourse (and some linguistic and semiotic aspects), as well as instances of psychologised and critical discourses in relation to an adapted version of Skelton’s framework of meta-understandings of teaching and learning in higher education (without using the term ‘excellence’) and the relevant literature. The discourses have emerged out of group and individual responses to a developing assessment rubric and specified questions. Our analysis attempts to show that the discourses enacted in hybrid genres – and associated social identities – embody differing epistemologies and purposes of teaching, learning, assessing and responding practices and misconceptions of language and literacies and responsibilities within the project. Given changes in discourse practices that have occurred over time, we consider some implications for imperatives of transformation and make recommendations in a context of dominating discourses.

Introduction

The authors of this article are situated on the Summerstrand North Campus (previously the main campus of the Port Elizabeth Technikon) of the merged Nelson Mandela Metropolitan University (NMMU). Since 2010, we have worked with each other in a project, which the Dean of the Faculty of Engineering, Built Environment and Information Technology (EBEIT) has called (for short) HEDS-TL. This collaborative project between (in this case) the Department of Mechanical Engineering (ME) and a writing centre, which falls under the Faculty of Higher Education Access and Development Services (HEADS), aims to make explicit and theorise teaching and learning (TL) through language and literacies in and across Engineering disciplines. The acronym HEDS in the title of the project, using the plural (‘S’), represents three different academic structures, namely HEADS, EBEIT and the Department of Applied Language Studies (DALS), which falls under the Faculty of Arts.

¹The NMMU is made up of seven campuses (six in Port Elizabeth and one in George) and was established in January 2005 after merger processes between university and technikon campuses.
We recognise as authors that if we hope to achieve shared understandings of ‘academic citizenship’ (Shils, 1997; Macfarlane, 2007), bringing together different participants, relations, processes, texts (both spoken and written) and discourses into ‘dialogue’ “in the richest sense of the term” (Fairclough, 2003, p. 41), we not only need to make explicit and theorise our practices, but also acknowledge very real differences in perspectives from our positions in disciplinary fields of study (ME and teaching and learning of literacies in English). Our methodology of discourse analysis thus identifies, analyses and critiques a dominant traditional discourse and how it represents, for example, knowledge, space, time, colour and agency in terms of linguistic and semiotic (meaning making) aspects (Fairclough, 2003), as well as instances of psychologised and critical discourses in relation to an adapted version of Skelton’s (2005) framework of meta-understandings of teaching and learning in higher education and the relevant literature. Our analysis attempts to show that the discourses – “ways of representing” elements of the world from differing perspectives or positions (Fairclough, 2003, p. 27) – embody differing epistemologies and purposes of teaching, learning, assessing and responding practices and misconceptions of language, literacies and responsibilities within the project.

The discourses are associated with hybrid (mixed) social identities or “ways of being” in the world, such as teacher/researcher of discourses (Anne), teacher/supervisor/researcher in ME (Hannalie) and lecturer/supervisor and head of department of ME (Pat). Moreover, the discourses are enacted in a ‘chain’ of linked, hybrid and ‘situated genres’ or “way[s] of acting and interacting linguistically” and discursively (Fairclough, 2003, p. 17), such as group and individual responses to questions (specified in the analysis) and to a developing assessment rubric (table or grid) for laboratory reports. The configurations of discourses, social identities and genres combine in specific networks of ‘social practices’, that is, relatively stable forms of activity (Fairclough, 2003), in this case, the teaching, learning and assessing of, and responding to, literacy practices in modules, which form part of the National Diploma programme in ME pegged at level 6 on the current National Qualifications Framework (NQF) of certification in the country. The Diploma comprises four semesters of academic study and focuses on “practical skills” and one year of experiential training (Case, 2006, p. 4).

We indicate some shifts in practices that have occurred over time and attempt to show that collaborating in and across disciplinary discourses and boundaries is a challenging process, particularly in a context of dominant, globalising and national discourses in a post-apartheid country, which have become institutionalised in specific ways, such as modernist binary2, neoliberal managerial3, performative4, quality assurance4, structural-functional and deficit

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1 English is the dominant language of teaching and learning in South African higher education (Yeld, 2011), despite multilingual policies being established in universities, such as the NMMU (2005).
2 Modernist binary discourses include those between, for example, ‘academic’ or ‘non-academic’ (articulated, for example, in the Higher Education Act of 1997) and ‘skills’ or ‘literacies’.
3 Neoliberal managerial discourse in the global, capitalist, knowledge-driven economy conflates “freedom of the market” with political freedom (Harvey, 2005, p. 2). This not only facilitates “conditions for profitable capital accumulation” for elites (ibid), but also shifts participants’ identities from democratic and academic citizen to utilitarian consumer and entrepreneur of commodities (Mollis & Marginson, 2002), which destroys solidarity, social responsibility and critique (Davies, 2005).
4 Skelton (2005) links a performative discourse of ‘teaching’ (as part of educational discourses) to ‘excellence’ (as part of discourses of quality). According to Skelton, the performative discourse of ‘teaching excellence’ is for a meritocracy and its purpose is efficiency (p. 35). It is located in rules and regulations and the teachers’ role is to enforce standards (ibid). The indicative method of the discourse is work-based learning and its epistemology is ‘knowledge that works’. This denigrates educational theory” (p. 171) and suggests...
discourses. We conclude by considering some implications of the discourses of teaching and learning for transformation and recommend systemic changes.

**National and Institutional Context**

The *Introduction* to the Improving Teaching and Learning Resource (ITLR, 2004, p.1) of the independent Higher Education Quality Committee (HEQC) of the Council for Higher Education (CHE) defines teaching as “planned efforts to bring about or facilitate learning”. The CHE Resource on *Programme Planning, Design and Management* (ITLR No. 4, 2004, p. 103) claims that universities are increasingly adopting a holistic and integrated approach to teaching, learning and research (in the sense of making systematic enquiry public), even though such purposes and responsibilities are usually “distinct in institutional structures and processes”. When designing integrated programmes, the Resource encourages collaboration between mainstream and language disciplinary specialists to teach language proficiency and “critical – as opposed to reproductive – academic literacies” (CHE, 2004, p. 106) in “discipline-specific tasks” (CHE, 2004, p. 107). This requires intensive, scaffolded opportunities for students to interact with each other and with specialists, who can ‘model’ different kinds of discourses and mediate “timely, recurring and detailed individual feedback” (ibid). Such practices, as the Resource points out, are “labour intensive and time-consuming” and require relations of trust (CHE, 2004, p. 106).

Like Starfield (2000) and Beaumont et al. (2008), the Resource on *The Assessment of Student Learning* (CHE, ITLR No. 5, 2004) seems to conceive assessment as feedback practices (as an integral part of teaching and learning). Moreover, the Resource (2004, p. 124) advocates a ‘weak’, as opposed to a behaviourist approach to learning outcomes aligned to assessment criteria, which allows educators to interpret and judge meanings “in ways that are sensitive to disciplines and contexts”.

The Resource (No. 5, 2004, p. 123) also refers to extending assessment “beyond the summative” (“measuring, recording and reporting of end-point achievement”) and diagnostic (“indicating aptitude and preparedness for a course of study”) to formative or developmental assessment to strengthen and inform teaching and learning. It supports structured peer- and self-assessment for formative learning purposes to enable students to make sense of meanings of learning outcomes aligned to assessment criteria (CHE ITLR No. 5, 2004, p. 124).

At institutional level, the NMMU TL Policy (2010, p. 4), which was approved by Senate and Council in July 2010, adopts a humanising approach to teaching and learning. The policy also refers to building collaborative educational relationships to foster and achieve holistic learning and “complementary learning outcomes”. It also refers to recognising relationships between teaching and research (2010, p. 3), integrating (explicitly embedding) “the development of academic literacies and discourses” in “curricula, teaching, assessment, and feedback practices” (2010, p. 6) and “encouraging critical dialogue” (2010, p. 3).

**Theorising Teaching and Learning of Discourse Practices and Analysis**

Specialists assume that language and literacies are “irreducible” aspects of all social practices, such as teaching, learning, assessing and responding, so that discourse analysis and

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1 “dehumanizing changes” (p. 100). We do not include the performative discourse in Table 1 below because we only encountered it once during our research practices. It also appears to be associated with the social identity of being a senior manager, who does not necessarily teach and conduct research.

2 The discourse of quality assurance (which suggests certainty in an uncertain world) appears to intersect with what Vidovich et al. (2000) argue is the dominant discourse of quality as accountability, which has an external locus of control associated with centralised, bureaucratic administrative structures.
critique “always has to take account” of such activities (Fairclough, 2003, p. 2). The term ‘language’ (in the abstract) or ‘languages’ (in the plural), as Thesen and van Pletzen (2006, p. 2) elucidate, include “language as in which language” (English, in a multilingual context); “language as in semiotic [sign] system; language as in ‘discourse’”; “and as in ‘metalanguage’”, i.e., “ways of talking about” discourse practices, such as teaching and learning through language and literacies. As Gee (1990, p. xix) emphasises, language and literacies are “always and everywhere integrated with and relative to social practices constituting particular Discourses”. Gee (2003) defines big D Discourses (which we predominantly represent with a lower case d in line with common practice) as combined ways of knowing-valuing-being-feeling-believing-interacting and acting (listening, talking, reading, writing and thinking) using various objects and technologies, which are accepted by discourse communities in ‘semiotic domains’. These domains mix words and images or modalities (e.g., tables and figures) and colour (e.g., using a traditional red pen to mark and give feedback) to communicate distinct meanings.

Jacobs’ research (2005, 2007a, 2007b), on the one hand, problematises whether mainstream lecturers, who have mastered specialist, disciplinary discourses as ‘insiders’ to communities, such as mechanical engineering, are best placed to teach and model academic literacies (embodied in disciplinary discourses and enacted in what Fairclough (2003) calls ‘situated genres’) and to induct students into these in critical ways. On the other hand, Jacobs questions whether language specialists, who are ‘outsiders’ of disciplinary discourses are best placed to teach students to communicate and participate in such literacies, discourses and genres in adjunct or ‘stand-alone’ service projects or courses. Jacobs shows that lecturers’ knowledge and understandings of the patterns and workings of disciplinary discourses are tacit and that it is only through sustained interaction in structured and ‘safe’ spaces with language specialists, who view language as opaque (2007a, p. 77), that lecturers can see themselves from “an insider perspective from the outside” (2007a, p. 80), achieve meta-awareness of “generic structures and discourse patterns of their disciplines” (2007b, p. 872), understand knowledge, language and literacies as constituted in discourses, instead of as discrete and separate bodies of ‘content’ and ‘skills’, and, as far as possible, make what is tacit (such as discourses enacted in genres and inculcated in social identities) overt and explicit for students in purposeful, meaningful and critical ways.

Collaborative Teaching and Learning through Language and Literacy Practices

Previous South African case studies in engineering education on ‘collaborative pedagogy’ (Howard, 2009) from socialising and academic literacy perspectives (Lea & Street, 2006) focus on what Macfarlane (2007), in a context of the dominance of the notion of ‘teaching and learning as performance’¹, calls ‘pre-performance’ or ‘offstage’ phases (e.g., co-developing materials and joint planning of classroom practices) and ‘performance’ or ‘onstage’ phases (e.g., ‘team teaching’) in order to improve student learning and broaden ‘discursive identities’ (see, for example, Allie et al., 2009).

We (Anne and Hannalie) have also practised what we prefer to call collaborative ‘teaching and learning’ (to distinguish between university and schooling practices) through language and literacies, drawing from what Sfard (1998) calls ‘participative’ views of learning. For example, in the first and second semesters of 2010, we put much effort into designing,

¹ According to Macfarlane (2007, p. 49), ‘teaching as performance’ and ‘performatve teaching’ are different. The former uses “dominant methods” that privilege the metaphor of theatre to evaluate teaching whereas the latter does this in relation to its impact on economic performance and efficiency measures endorsed by quality management procedures of audit and control.
drafting and piloting an assessment rubric for writing laboratory reports. One of the ‘strategic’ purposes (Fairclough, 2003) of this developing, socially-situated and hybrid genre is to align teaching activities and learning outcomes with assessment criteria and anticipated levels of achievement (named in the rubric ‘not achieved’, ‘partially achieved’, ‘achieved’ and ‘distinction’ – the latter for unanticipated practices). A second strategic purpose is to make explicit what lecturers expect students to do when writing laboratory reports in terms of learning outcomes and criteria. We worked together on this genre for a variety of reasons. First, we could not find a suitable one, which makes language and literacy features of our different disciplinary discourses explicit. Secondly, we wanted to use the rubric to interact with a wide variety of discourse communities (academic developers, lecturers in DALS and ME, as well as undergraduate and postgraduate students) and to elicit responses to the rubric to inform our teaching, learning and research practices. Third, we wanted to enable more consistent ways of formatively assessing and responding to drafts of laboratory reports in and across disciplinary boundaries, so that readers on the ‘inside’ of the discipline (lecturers), as well as ‘outsiders’ (language and literacy educators and students) could formatively assess and respond to drafts and align different kinds of feedback – global (overall) and local (specific) – in different modes (oral and written). The purpose of diverse readers, such as peers, responding to – and formatively assessing – writing for learning is to enlarge students’ understanding of the concept of ‘audience’, to show that writing has ‘real’ communicative purposes, to enable students to make sense of learning outcomes, assessment criteria and levels of achievement, and to shift views of assessing and responding practices from dominant summative and norm-referenced assessment practices (whereby student achievement is compared to classroom peers) to include formative and criterion-referenced practices (whereby explicit criteria are used to assess student achievement). Anne also wanted to make teaching and learning through literacies, such as reading and writing, and formative assessment practices, visible in modularised and “already crowded, content-driven” curricula (Mitchell, 2010, p. 140). This is because more invisible teaching and learning practices (such as, tutorials for small groups and research into teaching) are ‘unbundled’ to ‘outsiders’, such as so-called ‘non-academic’ staff in writing centres. However, modularised curricula leave “little scope” for formative assessing and feedback in the truncated time of a semester before summative and norm-referenced assessment takes place (Macfarlane, 2007, p. 56). In addition, ‘unbundling’ erodes lecturers’ responsibilities in that ‘outsiders’ of mainstream disciplines are often expected to assume full responsibility for formatively assessing and responding to students’ drafts of writing in different genres, without necessarily knowing what lecturers expect from students, which implicit theories inform lecturer’s educational principles and practices and how lecturer’s teach, assess and respond to students’ literacy practices.

In the first and second semesters of 2010 and at the beginning of 2011, we further developed teaching and learning materials to cohere with the developing assessment rubric for writing laboratory reports, such as scaffolded topics for each practical experiment and a checklist in the form of questions for students to use as part of peer- and self-assessment. This means that the rubric forms part of a ‘chain’ of linked genres (Fairclough, 2003), which students are required to use during interactive teaching an learning processes of talking, listening, reading, writing and thinking in and out of class.

During the first semester of 2011, we planned times to work with each other in class with groups of up to 100 students with the help of postgraduate and undergraduate peers. For instance, we used class time to explain teaching and learning materials and concepts (such as ‘revising’, ‘editing’, ‘coherence’ and ‘context’) and how they linked together, and to guide
and support groups to read and use the materials through planning, drafting, formative assessing, responding, revising and editing practices. In class, Anne also analysed examples of sections of laboratory reports, such as introductions, in relation to specifications in the assessment rubric. In doing so, she asked students whether the exemplars specified the context of the experiment, its aims, why it was conducted and whether the examples introduced and referenced relevant theoretical concepts, background principles and methods used to understand and perform the experiment.

Data Collection
Our data, which we collected from 2010 to 2011, comes from a variety of sources, such as excerpts from the national and institutional literature and the following: a text (A) on a module, which a lecturer shared with Anne; evaluative oral responses in a group to the assessment rubric for laboratory reports, which most ME lecturers, including a language lecturer, three academic developers and a writing consultant participated in (2010); two postgraduate students’ written responses to the rubric (2010), discussions with lecturer B (2011) and first-year students’ written responses to the rubric, as well as drafting, formative assessing and responding practices. We asked guiding questions, such as: What might the effects of the rubric be on teaching learning, assessing and feedback practices? What is the possible relationship between ‘quality’ and ‘transformation’ in terms of the HEDS-TL Language Project? And what do you mean by the terms ‘quality’, ‘transformation’, ‘teaching’, ‘learning’, ‘assessing’, ‘language’, ‘meta-language’, ‘communicating’, ‘skills’, ‘literacies’, ‘discourses’ and ‘project’? However, we largely viewed our discussions with lecturers as ‘negotiated’ language and discourse, in which participants made meaning in context (Schwandt, 2000).

Framework of Discourses
The framework in Table 1 below construes the constructs of ‘teaching’ and ‘learning’ in terms of three discourses, which Skelton (2005, 35) identifies as ‘traditional’, ‘psychologised’ (following Malcolm & Zukas, 2001) and ‘critical’ meta-understandings1.

The dominant discourse, which has emerged during our practices, is a traditional discourse, which might be called a ‘received tradition’ of teaching, learning and assessing (cf. Christie, 1993). The purpose of this discourse, as Skelton (2005, p.35) points out, is cultural reproduction for the social elite, who view their teaching roles as disciplinary ‘experts’. The discourse is located in disciplinary knowledge and “associated with mastery of a discipline” through learning “approved knowledge” (Skelton, 2005, p.27) or what lecturers (including some language lecturers) call ‘content’. It views such knowledge as entirely separate and discrete from the teaching, learning and assessing of language and literacies, which are

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1 We make multiple changes to Table 1 based on our conceptions of discourse and analysis of data. First, we use the term ‘discourses’ in the title instead of ‘meta-understandings’. Second, we do not use the word ‘excellence’, even though it is widely used in official documents at the University, because only one participant (a student in 2011) mentioned variations of this word (“The feedback was excellent … It takes time to achieve excellence”). There also appears to have been little or no discussion of different meanings of discourses of ‘quality’, which include ‘excellence’, among educators, who participated in our research. A third change that we make is that we consistently collocate ‘teaching’ and ‘learning’ (even though teaching might not necessarily lead to learning). Fourth, in indicating the teacher’s role using the traditional discourse, we substitute the term ‘disciplinary expert’ for ‘subject expert’. According to Parker (2002, p. 374), a ‘subject’ has a concrete “knowledge base which can easily be constructed into a programme of knowledge acquisition and … of quantitative assessment”, whereas “a discipline is a more complex structure: to be engaged in a discipline is to shape, and be shaped by” the discipline, “to be part of a scholarly community, to engage with [peers] – to become ‘disciplined’”.

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conceived as relatively fixed, unitary, generic (and thus easily transferable), context- and value-free (neutral) sets of skills arising out of individual learning (Hannon, 2000). Street (1995, p. 215), drawing from Graff (1979), however, critiques this myth of ‘autonomous’ literacy.

**Table 1.** Three discourses of teaching and learning in higher education (cf. Skelton 2005, p. 35)

<table>
<thead>
<tr>
<th></th>
<th>Traditional</th>
<th>Psychologised</th>
<th>Critical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Who for?</td>
<td>Social elite</td>
<td>Individuals</td>
<td>Informed citizenry</td>
</tr>
<tr>
<td>Where located?</td>
<td>Disciplinary knowledge</td>
<td>Teacher-student relations</td>
<td>Material conditions</td>
</tr>
<tr>
<td>Epistemology?</td>
<td>Pursuit of truth</td>
<td>Subjective interpretation</td>
<td>Social critique</td>
</tr>
<tr>
<td>Indicative method?</td>
<td>Lecture</td>
<td>Group work</td>
<td>Participatory dialogue</td>
</tr>
<tr>
<td>Teacher’s role?</td>
<td>Disciplinary expert</td>
<td>Psycho-diagnostician</td>
<td>Critical intellectual</td>
</tr>
<tr>
<td>Purpose?</td>
<td>Cultural reproduction</td>
<td>Effective learning</td>
<td>Emancipation</td>
</tr>
</tbody>
</table>

In a group discussion to evaluate the assessment rubric (2010), lecturer A uses the traditional discourse as follows: “first and foremost we shouldn’t have to teach language skills and writing skills”. In using this discourse, lecturer A explicitly conflates ‘language’, ‘writing’ and ‘skills’ and separates these from approved knowledge. Even more explicitly, lecturer B (whose assertions we analyse in more depth in the next section) separates the teaching of writing and referencing of a laboratory report, as well as formative feedback from ‘approved knowledge’. The lecturer makes her/his view explicit in relation to existing structures in response to two questions: ‘Using an analytic approach (as required by FME.77.01 Pilot Project FEBEIT), how would you make explicit the roles and responsibilities and identities of lecturers (DALS, ME), students (undergraduate and postgraduate) and Writing Centre consultant in relation to the teaching, learning and assessing of literacies? How often would you revisit these roles and responsibilities?’

Lecturer B: DALS – Teach the rubric, how to write a laboratory report and referencing to students; Writing centre – provide feedback on writing from students; Student assistants – assist the writing centre to provide feedback on their writing. I would not revisit these roles (December 2010).

Lecturer B’s response is an example of the traditional discourse of teaching and learning intersecting with the dominant structural functional discourse, which assumes fixed and unified structures, functions and roles and common shared interests (cf. Frost, 2001). This, however, masks unequal relations of power and differences.

The traditional discourse of teaching and learning of lecturer B assumes that a universal foundational knowledge exists, which guarantees its truth or accuracy (McCormick 1994). In the group session, lecturer A (2010) also assumes such knowledge, in relation to ME, which is a natural science, when s/he questions which grade of schooling lecturers should begin teaching: “now where should we start now … at grade 8 and should we start now at grade 7? Where should we start?”.

The indicative method of the traditional discourse is the lecture (Skelton, 2005), which conceives teaching as ‘imparting content’ to students (using words, such as ‘put on’, articulated by lecturer D below, and italicised). Lecturers also tend to articulate simplistic
educational and communication theories, which entail transmitting what they say to learners. In a discussion with Anne, lecturer B, for instance, states: “I just try and get my message across” (May 2011).

The traditional discourse, as Kalantzis and Cope (1993, p. 44) explain, means that lecturer talk “exceeds student talk”, “so chairs and tables are arranged in rows facing the … board”. The lecturer also “interacts with the whole class rather than groups” (ibid). This aspect of the traditional discourse is articulated in an individual discussion, as well as a document on a module, in which lecturer B states: “I sometimes just talk” (2011) and “provide an environment” in which “students must feel comfortable to ask questions” (text A, 2010).

The theory of learning underpinning the traditional discourse appears to be behaviourist (using words like ‘habits’ instead of practices), which Luckett and Webbstock (1999, p. 3) call “outdated behaviourist psychology” (as part of psychologised discourse). Behaviourist theory assumes that overt behaviour can be ‘measured’. This is closely linked to traditional objective testing (Shephard, 2000), which assigns a score based on accurate ‘content’. The traditional discourse also assumes that frequent tests are the way to measure whether students have mastered elements of the curriculum and are thus isomorphic to learning, that is, “tests = learning” (Shephard, 2000, p. 5). The dominant summative and norm-referenced assessment practices articulated in the excerpts below conceive of processes and practices of writing a laboratory report as a test for students, who are marked individually, to demonstrate approved knowledge:

Lecturer C: Now, I’m … talking about … summative assessments. Like, for example, the table of contents, the introduction, period. We don’t even allocate marks for that. What we look at specifically is [calculations of] results and discussions because that shows us what they know about the topic because they tend to just copy semester guides and their peers (they know each other). So those – the experimental set up – those things [in the assessment rubric] – it is the results, calculations and discussions – those are the issues – the way that the test would work (2010).

Lecturers C and D privilege products – and repeated summative tests in lecturer D’s case below – over writing-to-learn processes. Lecturer D also makes explicit what s/he expects in a laboratory report, but the statements come over as teacher-centred, which can happen when trying to make practices explicit. The lecturer conceives of practices of writing a laboratory report in terms of students demonstrating approved learning outcomes, which we refer to below in terms of the psychologised discourse.

Lecturer D (after participants in the group discussed using a template for writing laboratory reports): I think that you are not approaching this effectively enough. After 20 years of doing practicals … I tell those students exactly what their report must look like. So I tell them what I expect from the aim, the objectives, the procedure. I even give them that because they cannot go into engineering now without studying the procedures because then they are going to get into them and I am in trouble. The next thing I put on them is that a report must be no longer than 5 pages (2010).

Anne: that’s [i.e., the particular learning outcome relating to the length of the laboratory report] referred to] under editing and technical requirements [in the assessment rubric].

Lecturer D: I also tell them that 50% of the marks will go towards results and discussions and that’s it. And that’s all I will mark. I will critically review his [sic] results section and his [sic] discussions section because if I review the procedure, I just will give my own version. And that is the reality. You can fit in so much work in so much time – to do anything more than that. You’re busy. So I then assess that and if they get less than the mark – it is outcomes-based – they have to re-write the discussion. I will tell them “this and this is wrong. You go and re-write” because to my eyes you cannot focus on less than that because this is an outcomes-based thing they need to rewrite it - but there I can do with a language test. And also I am not a
language person. … But what I am saying, to get back to the discussion thing, I expect the guy [sic] to write and discuss the introduction, the aims, results and conclusions. If I pick up examples I will show you that the aims and the methods and procedures [are] exactly the same. That’s why I stopped marking that.

The epistemology (or theory of the nature of knowledge) underlying the traditional discourse assumes that there are fixed, objective ‘facts’ and universal ethical and ‘social truths’ in the world” (Kalantzis & Cope, 1993, p. 42). In practice, this means that certain sections of writing a laboratory report are taken-for-granted and a universal truth is that when students experience difficulties, the fault lies in lecturers (“I am in trouble” - italicised above) or language specialists (who are required to teach language and writing separate from disciplines) or the weaknesses of students themselves (as part of dominant deficit discourses, which can pathologise people). The epistemology of assessment translates into lecturers ticking sections of laboratory reports (using the ubiquitous red pen) to indicate marks (grades). The effect of this and saying “this and this is wrong. You go and re-write” (lecturer D, italicised above) is that most participants articulate a reproductive view of knowledge and ‘skills’, focusing on ‘correct’ answers to established truth (Tsai, 2002). Many students, for instance, consistently refer to “correcting” and “checking for errors” and “fix[ing] errors in the lab report and all the mistakes I have made in it” (document B, 2011). Yet, errors suggest myths, since teaching knowledge through language and literacies does not just refer to correctness and “one-right answer” (Larsen-Freeman, 2003, p. 59).

There have, however, been some changes in conceptions that have occurred over time in terms of what counts in teaching, learning, assessing and responding practices in relation to laboratory reports. For example, Hannalie wrote the following:

I have been convinced that a laboratory report is not just about calculating the results but the language and coherence of the report is just as important (December 2010).

Similarly, in response to a question asking students to explain what you have learned during formative assessing and responding processes when writing a complex laboratory report, a student wrote:

A lab report is not all about theory and calculation, it involves an introduction, contents page and references too, which are equally as important (May 2011).

A second associated discourse, which emerges from the excerpts above, is a psychologised one, which, Skelton (2005, p. 31) locates in individual teacher and student relations. Lecturer B’s assertion, namely that “students must feel comfortable to ask questions” (text A, 2010), could imply such relations. However, in lecturer D’s statements above, different learners are classified homogeneously as ‘students’ and as subject to the action of the first person ‘I’, using distancing words (‘those students’), the third person (‘they’ or ‘them’) and male forms of language (e.g. the possessive ‘his’), which do not include or regard all students as active participants of teaching and learning (as articulated in critical discourse).

Skelton (2005, p. 31) further associates the psychologised discourse with achieving learning outcomes. Yet lecturer D links outcomes to summative marks and percentages – or “grades, numbers, averages” to use the words of Malcolm (1999, p. 91). Spady, however, separates grades associated with traditional norm-referenced assessment from his behaviourist position of outcomes-based education (cf. Malcolm, 1999). The discourse of lecturer D is thus predominantly traditional: s/he appears to view learning as objective and “coming from outside” of students and not necessarily from what Malcolm (1999) articulates as thoughts, mental processes, understandings, beliefs and attitudes (embodied in differing discourses). Moreover, the lecturers, in this case, do not (implicitly or explicitly) refer to the method of
group work, the role of psycho-diagnostician, the purpose of effective learning or the epistemology of ‘subjective interpretation’ of the psychologised discourse.

A third discourse that has emerged is a critical discourse with an epistemology of social critique. This discourse is for informed citizens. This would include the notion of ‘academic citizens’ in Macfarlane’s (2007) sense of social and ethical obligations and responsibilities and political literacies to participate in decision-making processes in and across discourse communities at different levels in and outside of universities. Lecturer B (May 2011), for example, critiques the material conditions of students, many of whom cannot afford textbooks, food and transport costs to travel to campus in order to participate in practices, such as orientation. This, however, does not go far enough in that a critical discourse requires educators to act on and collectively contribute towards changing such material conditions (Burbules & Berk, 1999). The lecturer also critiques her/his own teaching, learning, formative assessing and feedback practices:

Lecturer B: If you take a video of me teaching in class, you will see that I need to make what I say much more explicit and change how I explain and sequence concepts. I often reflect about this every semester. I also need to take more responsibility for formative assessment and feedback in the process of laboratory report writing (May 2011).

This suggests that the lecturer views her/his practices from ‘the outside in’ while working with Anne. In this respect, Hannalie (2011) also writes: “By having discussions with you and you asking questions makes it easier for me to become the ‘outsider’”.

**Misconceptions of Language, Literacies and Responsibilities**

In our discourse analysis in the previous section using an adapted version of Skelton’s framework, we highlight that lecturers largely conceive of language and literacies, such as writing, simply as ‘skills’, and separate language and literacy practices from approved knowledge as part of the dominant traditional discourse of teaching and learning. The NMMU TL Policy (2010, p. 4) also refers to both ‘language skills’ and ‘communication skills’ (the latter in terms of the University’s Generic Graduate Attributes Profile) and the Engineering Council of South Africa (2009, p. 4) refers to ‘communication skills’, defining this as “the ability to communicate lucidly, accurately and with confidence”. This means that construing ‘language’ and ‘communication’ as ‘skills’ in the sense of abilities, which individuals either possess or do not possess, is a widespread misconception, which is not confined to ME lecturers. We also highlight that lecturers resist that they teach language and literacies as part of their disciplinary discourses. Lecturer B (May 2011) asserts that s/he knows that s/he is “a teacher of language”, but hesitates to use that notion because she is “not a language practitioner”. Indeed, the preposition ‘of’ suggests that the lecturer is qualified to teach language or about language and Anne thinks that she needs to make analytical distinctions more explicit, for example, between ‘teaching and learning language’ and ‘teaching and learning about language’ on the one hand and ‘teaching and learning through language’ on the other (cf. Halliday, 1985) and to explore these notions with lecturers. As Cope and Kalantzis (1993, 7) point out, a person does “not have to know about language” to use language to teach and learn.

Our discourse analysis in the previous section further shows that Lecturer B assigns fixed roles, responsibilities and texts (such as the developing assessment rubric) to ‘outsiders’ of disciplinary discourses in relation to the dominant structural-functional discourse and the perceived purposes and responsibilities of structures, i.e., language lecturers in DALS must teach students the rubric and writing and referencing of laboratory reports and the writing
centre must “provide feedback” to students’ writing with the help of student assistants. These statements, however, assume that teaching writing and referencing of laboratory reports and “provid[ing]” formative feedback can be separated from the teaching, learning and assessing of disciplinary discourses. The statements also suggest that, by December 2010, the lecturer had not assumed the social identity of teacher of disciplinary discourses.

Boughey (2002) and Jacobs (2007a), for example, identify a further dominant misconception of language in higher education, which Christie (1993) calls ‘language as an instrument of communication’. Many lecturers, including language lecturers, take up this understanding (which is also widely used in texts at the university1) to refer in general terms to language as a “tool” of communication (Meeting 2011). Lecturer B, for example, states as follows:

Lecturer B: Because lots of concepts are involved in the context of the subject, language becomes more important as a tool [for communicating] (May 2011).

This means that lecturers in disciplines tend to view language and literacies, such as writing, as simply a vehicle for (or instrument of) disciplinary communication (Bazerman et al, 2005) rather than as integral to disciplinary discourses.

**Implications and Recommendations**

The traditional discourse of teaching and learning, which intersects with instances of psychologised discourse in some examples of texts, reproduces dominant interests, practices and lecturer identities in and across disciplines of ME on campus instead of mooting collective interests and expanded and hybrid social identities, which includes that of teacher of disciplinary discourses. The traditional discourse and a dominant structural-functional discourse (with instances of psychologised discourse) also separates teaching and learning of ‘content’ from language and literacies. This accords with existing institutional structures, processes and practices and perpetuates misconceptions of language, literacies and responsibilities for disciplinary discourses. In other words, the dominant discourses work against holistic, integrated and collaborative teaching and learning practices between lecturers and language specialists to teach through language and ‘critical literacies’ in tasks that are discipline-specific.

The purpose of cultural reproduction of the traditional discourse is also contrary to imperatives of social and educational ‘transformation’, which aim to reverse the legacies and effects of social injustices in the country. As our analysis indicates, attempts at making expectations explicit can become teacher-centred and we need to be wary of simply focusing on products, demonstrating outcomes and traditional summative, norm-referenced assessment practices. Instead, lecturers and language specialists need to work together both formatively in terms of criterion-referenced assessment practices and summatively in terms of norm-referencing.

The psychologised discourse, according to Malcolm and Zukas (2001) dominates the research literature, but is also an inadequate response to imperatives of transforming teaching, learning assessing and responding practices through language and literacies. Like the performative discourse, it individualises teaching and learning and identifies universalising approaches to such practices, without considering the effects of dominant discourses, such as those referred to in the introduction and our analysis.

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1 For example, in discussing the University’s Language Policy (2005), the NMMU Audit Improvement Plan (2010), refers to a need for “a strong focus on student learning through the vehicle of language (additional emphasis in italics).
In this respect, language specialists and lecturers need to sustain their practices by working more systematically and systemic in and across Engineering disciplines and at programme level rather than only with individual lecturers, who teach modules. This entails, as the CHE ITLR (No. 4, 2004, p. 112) emphasises, working together at this level to design “innovative theory-based curricula” that make “epistemic, cognitive and discourse demands of … disciplines explicit” and open to questioning.

The discourses (traditional and psychologised, as well as dominant, regulatory discourses at meso and macro levels, for that matter) view teaching and learning practices as neutral and apolitical (Skelton, 2005, p. 34). Our title, however, suggests that we are working towards collaborative practices of ‘academic citizenship’ in ME and this locates us in a critical discourse, which focuses on changing dominant practices. Teaching according to a critical perspective, as Skelton (2005, p. 26) emphasises, is thus “inescapably political and at odds with the traditional emphasis on the disinterested pursuit of and dissemination of knowledge”. This does not mean abandoning rigorous academic practices. It does, however, mean taking on board criticisms of critical discourses (see Burbules & Berk, 1999, who compare and critique ‘critical thinking’ and ‘critical pedagogy’).

We believe that we are making a concerted and positive collaborative effort towards academic citizenship by changing how we teach, assess and respond to language, literacies and discourses and would like to conclude with a quotation from Postman and Weingartner (1971, p. 102), which was written 30 years ago, but with which we continue to grapple: “the key to [teaching, learning and] understanding a subject is to understand its language … what we call a subject is a language. A ‘discipline’ is a way of knowing, and whatever is known is inseparable from the symbols (mostly words) in which the knowing is [articulated]”.

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Admitting Engineering Students with the Best Chance of Success: Technological Literacy and the Technological Profile Inventory (TPI)

Melanie Luckay¹ and Brandon I. Collier-Reed²

Centre for Research in Engineering Education & Department of Mechanical Engineering, University of Cape Town, South Africa

¹mb.luckay@uct.ac.za, ²brandon.collier-reed@uct.ac.za

Abstract

In this article we describe the development and validation of an instrument – the Technological Profile Inventory (TPI). The instrument can be used to determine whether an applicant’s level of technological literacy is suitable for admission to an engineering programme. It might be argued that students entering an engineering programme should demonstrate a level of technological literacy, not sought during the admission process at most universities in South Africa, which rely primarily on the National Benchmark Testing instrument and the National Senior Certificate examination results. The items used in the TPI were drawn from a previous study (Collier-Reed, 2006) and were based on a rigorous qualitative analysis of interview data which was in turn informed by categories that emerged from a phenomenographic analysis. Data were collected from 198 Engineering and 237 Commerce students and the items subjected to exploratory factor analysis and Cronbach alpha testing. The result of the analysis was a modified version of the TPI where the data were found to be reliable and valid. The significant factors that define the ‘nature of technology’ were found to be the view of technology as either an artefact or related to a process, while those constituting ‘interaction with technological artefacts’ were direction and tinkering. A cohort analysis suggests that the anecdotal view of the possible difference in technological literacy between Commerce and Engineering students is supported by the data – Commerce students are statistically more likely to view technology as an artefact and interact with technological artefacts only when directed to do so, a less technologically literate position. Further work involves determining how to meaningfully combine the scores achieved by an individual completing the TPI to ultimately determine a score indicative of their applicable level of technological literacy.

Introduction

The South African school curriculum has been in a state of flux for more than a decade. The move to Outcomes-Based Education (OBE), which was initiated by Curriculum 2005, reached a milestone in 2008 with the first students matriculating with the National Senior Certificate (NSC). Concerns were raised when the Mathematics pass rate rose by 225% between 2007 to 2008, with significantly greater numbers of students achieving 80% or more. A similar, yet less drastic trend was shown in the Physical Science results. A panel of experts investigated this trend, concluding that, though the standard of the examination was appropriate, “there was a lack of differentiation at the level of A and B” (Department of Education, 2009). Therefore, it might be argued that A and B symbols in Mathematics and Physical Science might not be useful indicators of students’ success in engineering programmes, which might imply that in general the NSC as an admission differentiator might be less useful, as significantly more students were meeting minimum entrance requirements and being accepted into engineering programmes.
A number of universities in South Africa have adopted the National Benchmark Testing (NBT) instrument to provide complementary information to the NSC about admission choices. One of the objectives of the NBT is to “assess the relationship between higher education entry level requirements and school-level exit outcomes” (Higher Education South Africa, 2009, p. 1). One of the aspects included as part of this testing is Quantitative Literacy which aims to assess the “ability to manage situations or solve problems of a quantitative nature in real contexts relevant to higher education” (National Benchmark Tests, 2011). The University of Cape Town has for the 2012 admission cycle included scores achieved by applicants for the NBT in the composite score used for admission into engineering programmes (University of Cape Town, 2011, p. 33).

However, it might be argued that students entering an engineering programme should have more than just a demonstrated competence in Quantitative Literacy. They should rather have a certain level of technological literacy (of which Quantitative Literacy can be considered an aspect) in order to have the best chance of success in their chosen engineering programme. There are a number of reasons why students elect to study engineering (Reed & Case, 2003), with psychometric testing, bursary availability, school marks in Mathematics and Physical Science being some factors that bare little relation to a learner’s innate ability to engage in technological activities. In fact, it is quite possible that these potential engineering students are “technologically phobic” (Collier-Reed, 2006, p. 145) in that they experience interacting with technology as a “potentially intimidating experience” (Collier-Reed, Case, & Linder, 2009, p. 301). There is no claim being posited that should an engineering student on entry to university not have an advanced level of technological literacy that they will not be successful in an engineering programme. Rather, it has been argued in our earlier work (Collier-Reed, 2006) that learners with more simplistic levels of technological literacy may possibly be less suitable candidates for admission.

In order for applicants’ levels of technological literacy to be included as part of the suite of characteristics available for admission decisions to be based upon, it is necessary to be able to accurately determine just what these are at an individual level. This article introduces an instrument that can be used to determine an applicant’s level of technological literacy – the Technological Profile Inventory (TPI).

**What it means to be technological literate**

There have been many definitions of what it means to be technological literate. When the term was first used in this context in the 1970s, it was understood as something that incorporated the "knowledge and skills needed to function in a society dominated by technological innovation" (M. A. Rose, 2007, p. 35). In the years since, various researchers (cf. Barnett, 1995; de Vries, 2005; Devon & Ollis, 2007; Gagel, 1997; Hayden, 1989; Kahn & Kellner, 2005; Waetjen, 1993) and organisations such as the International Technology Education Association and the National Academy of Engineering (ITEA, 2000/2002/2007; Pearson & Young, 2002) have put forward their own definitions of what it means to be technologically literate. In previous work we have argued that for a person to be considered technologically literate, they must “understand the nature of technology, have a hands-on capability and capacity to interact with technological artefacts, and ... be able to think critically about issues relating to technology” (Collier-Reed, 2006, p. 15). It should be noted that action (or doing) forms a central part of all aspects relating to this definition.

Ingerman & Collier-Reed (2011) suggest that “what it is that is required in order to be considered technologically literate remains difficult to articulate as there is no one universal set of requirements that satisfies technological ‘literateness’” (p.138 - italics in original).
Furthermore, what people would need to *be* to be considered technologically literate “would vary depending on the socio-cultural context in which they found themselves” (ibid). Ingerman *et al.* go on to suggest that typical definitions (such as that presented above) focus nominally on the *content* of technological literacy and don’t recognise the importance of a complementary feature of technological literacy – *function*. They argue, drawing on the definition of function in the Oxford English Dictionary (Simpson, Weiner, & Oxford University Press., 1989) that the function of technological literacy is the “mode of action by which technological literacy fulfils its purpose” (p. 139).

Waetjen (1993) suggests that “people can, and do, live without the faintest notion of the nature of technology” (p. 5) – the intrinsic, or characteristic, qualities of technology (Collier-Reed, 2006, p. 15). Two Gallup surveys undertaken to assess what North Americans think about technology (L. C. Rose & Dugger Jr, 2002; L. C. Rose, Gallup, Dugger Jr, & Starkweather, 2004) support this view. In these surveys, more than two-thirds of respondents indicated that the first thing that came to mind when they heard the word technology was computers. This was followed by electronics at 5%. We would argue then that for many people, technology is seen as involving computers and technological literacy as involving “competence” (Barnett, 1995, p. 120) in the interaction with computers.

Given that engineering degrees by design lead to technologically focussed vocations, one could reasonably assume that seeing technology simply as computers is not useful. Although one could assume that a graduate attribute of an engineering programme should be technological literacy, we would argue that it would improve the chance of success of students in a programme if they entered with a more developed conception of the nature of technology and level of technological literacy.

**The Technological Profile Inventory (TPI)**

In our previous work, we interrogated the dimensions of technological literacy presented above and after a phenomenographic analysis of interview data described five qualitatively different ways of experiencing the nature of technology (Collier-Reed, 2006) and four qualitatively different ways of experiencing interacting with technological artefacts (Collier-Reed, *et al.*, 2009). These categories of description are presented in Table 1. We argue that collectively, these dimensions of technological literacy satisfy the core content requirements for what it means to be technologically literate.

**Table 1.** Ways of experiencing the nature of technology and interaction with technological artefacts

<table>
<thead>
<tr>
<th>The nature of technology is conceived of as:</th>
<th>Interaction with technological artefacts is through:</th>
</tr>
</thead>
<tbody>
<tr>
<td>An artefact</td>
<td>Direction</td>
</tr>
<tr>
<td>The application of artefacts</td>
<td>Instruction</td>
</tr>
<tr>
<td>The process of artefact progression</td>
<td>Tinkering</td>
</tr>
<tr>
<td>Using knowledge and skill to develop artefacts</td>
<td>Engaging</td>
</tr>
<tr>
<td>The solution to a problem</td>
<td></td>
</tr>
</tbody>
</table>

In order to be able to classify students relative to these categories, and hence ultimately to be able to describe their technological profile, we developed a series of statements that could be
used to interrogate students’ views on these dimensions of technological literacy. It was important when developing the statements to ensure that they were in fact representative of – or attributable to – the categories under consideration. In order to ensure this congruence, the interviews that were previously phenomenographically analysed were reanalysed with a focus now on the individual. Sections of an interview which related to a specific category were ‘assigned’ to it, resulting number of clearly defined statements pertaining to each category.

As an example of how the essence of a section from an interview was used in the development of a statement, consider the following extract that was classified as belonging to the category ‘Technology is conceived of as an artefact’:

Well, it’s a bit complicated, firstly. It’s very technological. It’s exactly what I was talking about, what I said complicated wires and things that you don’t understand, it looked like technology. (Italics in original)

From this interview extract, the following representative statement was constructed: Things with complicated wires and parts that you don’t understand are technology. The critical feature of the statements resulting from this process is that they originate from the interviewee’s own comments and are thus in the style to which they can relate. The draft TPI was defined by 41 statements constructed in this way. There were 25 statements relating to experiencing the nature of technology (see Table 2), and 16 statements relating to the experience of interacting with technological artefacts (see Table 3).

Table 2. Questions relating to the nature of technology

<table>
<thead>
<tr>
<th>Technology as an artefact</th>
</tr>
</thead>
<tbody>
<tr>
<td>39. Having wires coming out of things makes them technology.</td>
</tr>
<tr>
<td>06. Because a door has a handle and hinges and can be locked, is it technology?</td>
</tr>
<tr>
<td>38. A washing machine on a rubbish dump with no motor or wires is not technology. It is just a thing.</td>
</tr>
<tr>
<td>30. Things with complicated wires and parts that you don’t understand are technology.</td>
</tr>
<tr>
<td>19. Technology is all about computers and other electronic and electrical things like that.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Technology as the application of artefacts</th>
</tr>
</thead>
<tbody>
<tr>
<td>40. A door lock becomes technology when a key is turned in it and the levers move to lock it otherwise it is just a lock.</td>
</tr>
<tr>
<td>07. A map is technology because satellites were used to give the information needed to make it.</td>
</tr>
<tr>
<td>04. A CD is technology when you put the CD into a computer and then copy music onto it.</td>
</tr>
<tr>
<td>36. An amplifier or CD player becomes technology when it is switched on.</td>
</tr>
<tr>
<td>34. A television is technology when you can watch a movie on it using a signal from the air.</td>
</tr>
</tbody>
</table>
Technology as the process of artefact progression

31. Technology is when a product progresses and develops over time.
01. Technology is something that has advanced over time and that makes life easier for you.
21. The process that goes into making (for example) a running shoe makes the shoe technology.
23. Technology is the process of progressing from something like the horse-and-cart to a motorcar.
16. Technology is the changing or development of a product to help you in your life.

Technology as using knowledge and skill to develop artefacts

37. Technology is the planning and research of something and then the making of it.
27. Technology is using knowledge and skill to develop some product.
32. Something is technology because a person had a plan that was put into practice by making it.
14. Technology is about using scientific knowledge to make something that makes life easier.
22. Technology is using knowledge to evolve and develop to a product.

Technology as the solution to a problem

35. Technology is about solving a problem.
20. Technology is making use of knowledge people have about something and using this to solve a problem.
13. Technology is an idea that has been put into place by someone to help people.
09. Technology is coming up with an idea to solve a problem.
02. Technology is a person making something to solve a problem and improve quality of life.

Table 3. Questions relating to interacting with technological artefacts

<table>
<thead>
<tr>
<th>Interaction with a technological artefact is through direction</th>
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<tbody>
<tr>
<td>05. I always ask permission before I use some new technological thing in case I break it.</td>
</tr>
<tr>
<td>28. I would rather watch someone work with a complicated technological thing instead of trying to do it myself.</td>
</tr>
<tr>
<td>33. I always seem to do something wrong when I try to use technological things.</td>
</tr>
<tr>
<td>15. I would rather get someone else to work a technological thing. I might get it wrong or mess it up.</td>
</tr>
</tbody>
</table>
Interaction with a technological artefact is through instruction

24. If someone first shows me how to do something with a technological thing then I can use it.

17. With instructions, I would be able to find out how to do what I want with this technological thing.

25. When using technological things, instructions tell me exactly what to do – and then I can do it.

41. I can usually use technological things when I follow instructions.

Interaction with a technological artefact is through tinkering

11. When I see a new technological thing, the first thing I want to do is play around with it to see what it can do.

03. I would rather play around with a technological thing than waste time reading instructions about how to do it.

12. I like opening up technological things to see what’s inside.

08. It is fun figuring out how technological things work without being given instructions to follow.

Interaction with a technological artefact is through engaging

29. I like to understand a technological thing by playing with it as well as by reading more about it.

10. With a new technological thing, I read the manual a bit and play with it a bit – whichever helps me most.

26. Finding out how a technological thing works is easiest by reading the manual and playing around at the same time.

18. To find new features on the technological thing and understand it better, manuals often help.

A 41 item pilot instrument emerged from this analysis with the statements presented in Table 2 and Table 3 arranged in random order – the numbers alongside each statement indicate the order in which they were presented on the pilot instrument. The instrument was now subjected to wide-scale testing to confirm the validity and reliability of the items.

Exploratory analysis of the TPI

Data were collected from 435 students in May of their first year of study at the University of Cape Town. The groups were split between Engineering (198) and Commerce (237) students. These two groups were chosen because not only do both have similar admission criteria, but evidence suggests that the Faculty of Commerce is not typically in direct competition with
the Faculty of Engineering and the Built Environment for students (Donald, 2011). We would argue that the requirement to be technologically literate is more desirable in the latter.

Participants were required to supply biographical information in the form of their age, gender, and degree programme. From this information, it was determined that the sample consisted of 63% males and 36% females – five people did not indicate their gender. The average age of the students was 18 years 11 months ($SD = 2.89$, range = 16-29 years).

The participants were informed that the purpose of the study was to explore their ideas about technology. We administered the questionnaires personally to ensure consistency in the instructions given to the students and to answer possible queries. During the instruction session (which lasted on average 6 minutes), the students were told that completion of the questionnaire was voluntary (no student objected to completing the questionnaire), and that all responses were confidential. Participants were required to mark on a seven-point Likert scale (Cohen, Manion, & Morrison, 2000) their level of agreement with each item on a scale ranging from *Strongly Disagree* to *Strongly Agree*. The questionnaire took between 13 and 20 minutes to complete.

The data collected from the students were used to examine the validity and reliability of the TPI. As a first step, a factor analysis was performed to group or cluster variables (Field, 2005). In order to perform a factor analysis, an appropriate sample size is required. The sample size for the present study was appropriate as Tabachnick and Fiddell (2007) suggest that “it is comforting to have at least 300 cases for factor analysis” (p. 613), where in the present study the sample consists of 435 students. In addition, other authors suggest that the ratio of the items to subjects is of importance (Nunnally, 1978). Indeed, Nunnally (1978) recommends a ten to one ratio, that is, 10 cases for each item to be factor analysed. Others suggest 5 cases for each item (Tabachnich and Fiddell, 2007). On the whole, the data in the present study fit the requirements for both sample size and case to item ratio.

The data was imported into SPSS, the statistical analysis software package, and a principal component factor analysis using the varimax method of factor rotation was performed to obtain a small number of more unique indices. Initially, this analysis derived a nine-factor solution which accounted for 52.3% of the variance. Items with a factor loading of less than 0.3, and items whose factor loadings were low, were removed from further analysis. These items were thus of low value in contributing to the overall view of those completing the TPI. The remaining scales were subsequently re-analysed, and a six-factor solution was obtained accounting for 54.5% of the variance.

The factors emerged in line with the categories presented in Table 1 – which was not unanticipated as the items themselves were developed based on a rigorous qualitative analysis of interview data which was in turn informed by categories that emerged from a phenomenographic analysis (Collier-Reed, 2006). These factors were subsequently collectively named in line with the original categories described in Table 1 and are shown in Table 4. The factors contain items from Table 2 and Table 3 as follows: *Artefact* (items 39, 40, 38, 36, 34, 30); *Process* (35, 16, 14, 09, 02, 01); *Direction* (15, 28, 33); *Instruction* (24, 19); *Tinkering* (03, 08, 11); and *Engaging* (10, 29, 26). The eigenvalues ranged between 1.1 and 3.6.
Table 4. Factor loadings for a modified version of the TPI

<table>
<thead>
<tr>
<th>Item No.</th>
<th>Artefact</th>
<th>Process</th>
<th>Direction</th>
<th>Instruction</th>
<th>Tinkering</th>
<th>Engaging</th>
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<td>0.73</td>
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<td>09</td>
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<td>0.59</td>
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<tr>
<td>02</td>
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<td>0.57</td>
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<tr>
<td>Eigenvalue</td>
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<td>2.7</td>
<td>2.0</td>
<td>1.1</td>
<td>1.8</td>
<td>1.4</td>
</tr>
</tbody>
</table>

Factor loadings smaller than 0.30 have been omitted. $n = 435$

The analysis presented in Table 4 indicates that the items making up the factors relating to the nature of technology fall into two rather than the four categories presented in Table 1. The first is a category related to understanding technology in terms of *artefacts* (cf. the Gallup poll described earlier) and the other which recognises technology to be related to *process* and the solution to problems. The factors that emerge relating to interaction with technological
artefacts align very well with the categories described in Table 1 in three of the four instances.

For the revised 23-item TPI, a further index of scale reliability and validity were generated. Table 5 shows that the internal reliability – the Cronbach alpha coefficient – for the TPI scales ranged between 0.60 and 0.73.

Table 5. Cronbach alpha coefficient for the modified version of the TPI

<table>
<thead>
<tr>
<th>Category</th>
<th>Scale</th>
<th>No. of Items</th>
<th>Cronbach alpha coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature of Technology</td>
<td>Artefact</td>
<td>6</td>
<td>0.73</td>
</tr>
<tr>
<td></td>
<td>Process</td>
<td>6</td>
<td>0.68</td>
</tr>
<tr>
<td>Interacting with a Technological Artefact</td>
<td>Direction</td>
<td>3</td>
<td>0.71</td>
</tr>
<tr>
<td></td>
<td>Instruction</td>
<td>2</td>
<td>0.62</td>
</tr>
<tr>
<td></td>
<td>Tinkering</td>
<td>3</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>Engaging</td>
<td>3</td>
<td>0.60</td>
</tr>
</tbody>
</table>

Kline (1999) notes that although the generally accepted value of 0.8 as a Cronbach alpha coefficient is appropriate for cognitive tests such as intelligence tests, for ability tests a cut-off of 0.7 is more suitable. He goes on to say that when dealing with psychological constructs, values below 0.7 can, realistically, be expected because of the diversity of constructs being measured – as in the case of the present study. Overall, these results indicate that the internal consistency for the TPI is satisfactory for an exploratory study of this nature.

Taken together, the results from the factor analysis, as well as the index of scale reliability and validity (the Cronbach alpha reliability index) suggest that the Technological Profile Inventory is reliable and valid for use amongst the group that would be targeted as part of an admissions process and can therefore be used with confidence.

Cohort comparison based on TPI data

Notwithstanding the fact that the data collected were from a 41-item pilot instrument, it is possible to extract the responses received to the questions relevant to the updated 23-item instrument. In so doing, it is possible to perform a preliminary analysis of the differences between the Commerce and Engineering students as highlighted by the revised TPI.

A one-way between-groups multivariate analysis of variance (MANOVA) was performed to investigate group differences (see Table 6). Six dependent variables were used, namely, Artefact, Process, Direction, Instruction, Tinkering, and Engaging.

The results show that there was a statistically significant difference between the Commerce and Engineering students’ responses to the TPI on the combined set of dependent variables $F(6, 428) = 6.51, p = 0.000$. When the results for the dependent variables were considered separately, there was a statistically significant difference on the scales Artefact $F(1, 433) = 7.011, p = 0.008$; Direction $F(1, 433) = 19.57, p = 0.000$; and Instruction $F(1, 433) = 15.81, p = 0.000$. Closer inspection of the mean scores indicated for each of the three scales, showed that Commerce students showed higher levels of agreement with the statements in the scales Artefact ($M = 3.57$, $SD = 1.15$) compared to the Engineering students ($M = 3.28$, $SD = 1.05$); Direction ($M = 3.32$, $SD = 1.48$) compared to the Engineering students ($M = 2.73$, $SD =$
1.19; and *Instruction* \((M = 4.74, \ SD = 1.14)\) compared to the Engineering students \((M = 4.28, \ SD = 1.28)\).

**Table 6.** Differences between the responses of Commerce and Engineering students (MANOVA)

<table>
<thead>
<tr>
<th>Scale</th>
<th>Commerce</th>
<th>Engineering</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
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<tr>
<td></td>
<td>M</td>
<td>SD</td>
<td>n</td>
<td>M</td>
</tr>
<tr>
<td>Artefact</td>
<td>3.57</td>
<td>1.15</td>
<td>236</td>
<td>3.28</td>
</tr>
<tr>
<td>Process</td>
<td>5.38</td>
<td>0.81</td>
<td>236</td>
<td>5.37</td>
</tr>
<tr>
<td>Direction</td>
<td>3.32</td>
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<td>2.73</td>
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<tr>
<td>Instruction</td>
<td>4.74</td>
<td>1.14</td>
<td>236</td>
<td>4.28</td>
</tr>
<tr>
<td>Tinkering</td>
<td>5.23</td>
<td>1.23</td>
<td>236</td>
<td>5.36</td>
</tr>
<tr>
<td>Engaging</td>
<td>4.97</td>
<td>1.27</td>
<td>236</td>
<td>4.88</td>
</tr>
</tbody>
</table>

* \(p<0.05\)

**Discussion**

The statistical analysis undertaken on the 435 student responses collected suggests that the factors to emerge are valid and reliable. It has already been discussed how the association between items – and hence the factors – align with the phenomenographic categories determined in an earlier study (Collier-Reed, 2006).

A careful consideration of the factors as they emerged from the analysis (see Table 4 and Table 5) suggests that the factor associated with the interaction with technological artefacts through *instruction* was possibly less useful in measuring what was originally intended by this category. The focus of this category is on receiving “instruction via some means which enables the interaction with an artefact” (Collier-Reed, et al., 2009, p. 299). The two items to emerge that could potentially constitute this category are from Table 3: 19) *Technology is all about computers and other electronic and electrical things like that*; and 24) *If someone first shows me how to do something with a technological thing then I can use it*. While item 24 is clearly related to the category as described, item 19 is less so and yet the Cronbach alpha coefficient (see Table 5) was 0.62 which suggests that the internal consistency of these two items can be considered reasonable – albeit only just so.

It was argued previously that a Cronbach alpha coefficient greater than 0.70 in an analysis is preferred, but that a coefficient of more than 0.60 is also acceptable in Social Science studies of this nature. Table 5 shows the co-efficients achieved in this analysis with the co-efficients for *instruction* and *engaging* having the lowest values (0.62 and 0.60 respectively). The research objective described in the introduction relates to developing an instrument that can provide useful data on an applicant’s level of technological literacy to help in the admission process. Careful consideration of the factors as they emerged suggests that it would be possible to omit *instruction* and *engaging* from the instrument without a reduction in the value of the information obtained.

The two factors that would remain as part of the ‘interaction with technological artefacts’ categories – *direction* and *tinkering* – are the essence of the possible ways of interacting with technological artefacts. In our previous work (Collier-Reed, et al., 2009) we have described the experience of interacting with a technological artefact through *direction* as
the result of a directive by someone. It is not something that happens spontaneously as there is a reluctance to making a first move towards approaching it. This category describes the experience as being on the outside looking in towards a technological artefact as a reified object; the artefact is placed on a ‘pedestal’ in an exalted, unapproachable position. (p. 298)

**Tinkering** on the other hand is described as being characterised by a self-initiating interaction with a technological artefact by beginning to tinker with it. … [T]here is no need for instruction to enable this interaction. There is no sense of being intimidated by anything to do with the artefact. … [They] recognise that an artefact has a variety of functions and set out to determine what they are and make the artefact operate. (ibid, p. 299-300)

Turning our attention to the factors that define the nature of technology, Table 5 indicates that viewing technology as either an artefact or as related to a process achieved Cronbach alpha coefficients of 0.73 and 0.68 respectively. The categories described in Table 1 for the nature of technology are fourfold, viz technology as an artefact, the application of artefacts, the process of artefact progression, using knowledge and skill to develop artefacts, and the solution to a problem. In the first two categories, the nature of technology is seen primarily in terms of the artefacts themselves. In the final three categories, artefacts are simply part of what makes up the meaning of technology and that here the nature of technology is seen as collectively involving the application of knowledge, design, and production in the development and use of objects, systems, and processes to satisfy human needs – an altogether more advanced conception of the nature of technology.

When one considers the cohort analysis between the Commerce and Engineering students’ responses to the TPI, three factors showed a statistically significant difference, namely, artefact, direction, and instruction (see Table 6). It has been argued above that instruction is a factor that will not be taken forward as part of the TPI.

While considering the nature of technology, one could anecdotally expect that Commerce students may be more inclined to conceive of technology as being related to artefacts than Engineering students. It could be argued that students electing to follow a programme in engineering do so in part because they recognise that technology – the core of their intended profession – does not simply revolve around artefacts, but rather involves all the aspects described earlier, viz the application of knowledge, design, and production in the development and use of objects, systems, and processes to satisfy human needs. The results presented in Table 6 empirically support this anecdotal view. Although the students had a similar mean score for the process factor (3.57 vs 3.58 for Commerce and Engineering respectively), there was a statistically significant difference between the students with respect to the artefact factor. As expected, Commerce students were statistically more likely to agree that the nature of technology was related to artefacts.

Turning our attention to the factors related to the ‘interaction with technological artefacts’. The argument could be made that due to the nature of the profession, Commerce students may be less inclined to tinker with technological artefacts and rather interact because they are required to do so based on a particular situation in which they find themselves. In Table 6, the mean scores for tinkering (5.36 vs 5.23 for the Engineering and Commerce respectively) suggest that engineers more strongly agree with this factor – although not statistically significantly so. However, there is a marked difference in the means of the direction factor. Here, direction is statistically significant between the two groups with means of 3.32 and 2.73 for the Commerce and Engineering students respectively. Commerce students more strongly agree that interaction with technological artefacts is through direction.
Although we argued above for the exclusion of the *engaging* factor from the TPI, it is useful to nevertheless consider this factor as the mean scores are contrary to what we would consider to have been the anticipated outcome for the two groups (see Table 6). One could have expected, given that experiencing interacting with technological artefacts through engagement is the most complex or advanced (Collier-Reed, et al., 2009, p. 298), engineering students would have had a stronger agreement with this factor than commerce students. This turned out not to be the case with Commerce students having a mean of 4.97 and Engineering students a mean of 4.88 for this factor. Although the one-way between-groups multivariate analysis of variance did not show the difference between groups at the level of *p*<0.05 to be significant, the fact remains that anecdotal evidence would suggest that this is an outcome that should be investigated through further research – or omitted as we argued earlier.

**Concluding remarks**

This article had the objective of describing the development and testing through exploratory factor analysis of an instrument – the *Technological Profile Inventory* (or TPI) – for use in collecting information on specific dimensions of a student’s level of technological literacy. We argued that this information could meaningfully be used to complement existing admission data, including the applicant’s NSC scores and their performance in the NBT, to help ensure that students admitted to an engineering programme had the greatest chance of success. The outcome of the analysis suggests that the instrument does collect useful data that can be used to differentiate between students who entered two different faculties.

The next stage in this project is to collect data from across the different faculties to confirm what the results we have presented suggest. Furthermore, we need to determine how to meaningfully combine the scores achieved by an individual completing the finalised instrument to ultimately determine a score indicative of their applicable level of technological literacy.

**References**


An Evaluation of the Use of Supplemental Instruction in Third Level Engineering Studies

Rosanne O’Hara¹ and Jonathan Pocock²

¹Academic Support and Advancement Programme (ASAP), Faculty of Engineering, University of KwaZulu-Natal, Durban 4041; ²School of Chemical Engineering, Faculty of Engineering, University of KwaZulu-Natal, Durban 4041

¹oharar@ukzn.ac.za, ²pocockj@ukzn.ac.za

Abstract

This paper examines the use of Supplemental Instruction (SI) in two third year Electrical Electronic and Computer Engineering modules at the University of KwaZulu-Natal from 2009 to 2011. In both modules, SI sessions were carried out to supplement the module teaching and provide a peer-led collaborative learning environment for students. Data collected showed that students who attended SI sessions on a regular basis consistently achieved higher pass rates than students who did not. Further examination of student records, however, revealed that although students attending SI sessions were more likely to pass these specific modules, there was no determinable positive effect on their later academic performance. A survey of SI attendees carried out in 2011 showed that although students found SI to be a positive experience, there is little student perception of the development of transferrable skills and SI is rather being viewed as a way to pass a specific module.

Introduction

Systems and Simulation and Control Systems are two modules run by the School of Electrical, Electronic and Computer Engineering (EECE) at the University of KwaZulu-Natal (UKZN). Both modules are taken by third year students in Electrical, Electronic, computer and Mechanical Engineering. The modules are prerequisites for a number of other modules and therefore not passing one could severely impact upon the student’s academic progression. The modules are seen to be problematic in so far as the pass rates commonly drop below 60% and class sizes have passed the 300 mark in the past 5 years. The course material (such as modelling, use of Simulink and the numerical methods) is also very new to students and although there are tutorials in place students tend to get left behind and are therefore more likely to feel despondent and even fail. In order to assist students in passing these modules, Supplemental Instruction was implemented first in Systems and Simulation in 2009 semester one and secondly in Control systems in semester two 2009. Supplemental Instruction has since been implemented in both modules in 2010 and continues to be used in 2011.

Theoretical Framework

Supplemental Instruction (SI) is a series of weekly review sessions for students taking historically difficult modules. SI is provided for all students who want to improve their understanding of course material and improve their marks. SI is run by The Academic Development and Advancement Programme (ASAP) within the Faculty of Engineering. Each school has an Academic Development Officer (ADO) who among other things acts as a manager of SI leaders (students who previously attained a grade of higher than 70% for the relevant module and who therefore act as a role model for other students). These SI leaders are extensively trained at the start of each semester.
The sessions are facilitated by the SI leaders, who model the appropriate kind of strategies and thinking needed for success in the discipline. The major difference between SI and tutoring is that the Leader neither teaches nor coaches; his or her task is solely to facilitate the group learning process through maintaining the direction and momentum of the group's exploration of a principle and/or its application by providing material to work on and encouraging all its members to participate meaningfully in the discussion.

According to Hillman (1996) The SI system is designed to focus precisely on understanding and skill development and greatly improves the success of these processes by getting students to work together in groups and enabling them to build their own understanding by participating actively in groups in an informal and non-threatening environment. Effectively, this is collaborative learning with the students both refining their understanding of material which has been covered in a module, and gaining experience in problem solving within the context of the material being studied. This can be compared to the theory of Vygotsky (1978) regarding the Zone of Proximal Development (ZPD) with the SI leader acting as an experienced other who challenges students to extend their ability in the subject through interaction with their peers. Similarly, according to Ardendale (1993) Piaget’s theory of Constructivism is that students must actively construct their own knowledge in order for them to be able to use it in a productive way. If students do not have a formal (abstract) level of cognitive development and instead have a more concrete operational level of development they will not be able to assimilate what is being taught to them by the usual abstract method of teaching. The SI leader’s task is therefore to guide students’ as they raise their operational levels.

Supplemental Instruction began in the 1970s in the United States as an intervention championed by the University of Missouri-Kansas City. The university itself is the world centre for SI and provides training to promote this as an academic development initiative worldwide through their centre (UKMC, 2011).

SI has been shown to be effective in improving the grades of students who attend regularly, and to reduce the percentage of students who fail or withdraw from courses (UKMC, 2011), and has been used as a system to increase student retention across the world. It is not, however, simply a form of tutoring as it seeks to develop meta-skills in participants.

The US National Data Summaries (Anon, 2011), (Anon 2, 2011) provide data for over 60 000 and 119 000 SI and non-SI attendees across US institutions from 1998-2006. Although there are two different reports, the findings are the same in that SI improves the grades of those students who participate and results in lower rates of withdrawals, lower grades and fails in the modules (‗DFWs’ – D-grade, Fail or Withdrawal).

With regard to improving higher order thinking skills (HOTS), although there is significant literature which claims that SI can assist students in developing these (see for example Blanc et al., 1983; Congos and Schoeps, 1993; Arendale, 1994, McGuire 2006), due to the difficulty in statistically proving or disproving such claims, little evidence is available.

Within South Africa, the Nelson Mandela Metropolitan University has been the national office for training and promotion of SI since the 1990s. Published literature is also available from the use of SI at Rhodes University (Vorster, 1999) and the University of the Witwatersrand (McCarthy et al., 1997) (Smuts, 2003). The local literature reflects the International belief that SI can be a useful academic intervention to assist in improving pass rates in modules that students traditionally find difficult, however, there is some disagreement regarding the development of transferrable cognitive skills through SI. McCarthy et al.
(1997) found that although SI could be perceived as a positive learning experience and could benefit disadvantaged students, overall there was no statistical significance in improved grades in other groups but rather a positive trend, and no evidence of specific improvements in transferred skills.

One area where there is a significant lack of literature is in later year use of SI. Most studies tend to focus upon first or at most second year students taking four year degree programmes. This study looks at the effectiveness of SI and its impact on the ‘meta’ skills amongst third level engineering students. The research questions that were investigated were:

Does regular attendance at SI sessions assist students in passing a given module?
Does SI have an impact upon grades achieved in subsequent studies (in comparison to previous performance)?
Do students perceive SI to improve their study skills?

To answer these questions, both quantitative data (pass rates for attendees and non-attendees, student grades pre- and post- SI) and qualitative data (questionnaires and interviews) was collected as detailed in the next section.

Data Collection
The study was based upon both quantitative and qualitative data collected through two means.

Quantitative Data
The quantitative data consists of pass rates from two consecutive cohorts of students studying 3rd year Electrical, Electronic, Computer and Mechanical engineering. All four of these disciplines have two common high risk modules (ie. high risk of student failure) in the 3rd year – Systems and Simulation, and Control Systems 1. SI was implemented in 2009 and 2010 in both of the modules (Systems and Simulation is in first semester, Control Systems 1 in second semester) and data on pass rates and SI attendance collected from attendance registers and the university results database.

A second set of quantitative data was used to determine whether SI had any long term effect on the academic success of students. A list of 130 students who attended at least one SI session in Systems and Simulation during 2010 was gathered by way of attendance registers. This list was then sorted by final mark (module and exam mark combined) rather than by number of times a student attended SI sessions. Students were chosen in interval of fives so that out of 130 students, 26 were used as data. This method of sorting the data removed any possible bias due to year of entry at the university or registered programme. The list is comprised of diverse students and was made up of both male and female students with differing overall degree performance and background. Average performance before and after attendance at SI was then determined from an average mark for all registered modules.

Qualitative Data
At the end of the 2011 semester, students taking Systems and Simulation were surveyed to gain an understanding of the student perception of SI. The questionnaire did not focus only upon SI (it covered all methods of academic support available within the faculty) but specific questions were used to determine effectiveness of SI from a student perspective. The questions were:

1. SI sessions helped me understand this module better. (Question 8)
2. SI sessions helped me improve my performance in this module. (Question 9)
3. SI sessions helped me understand other modules better by using the skills learnt in SI sessions. (Question 10)

4. Sessions helped me improve my performance in other modules by using the skills learnt in SI sessions. (Question 11)

Students were asked to rate whether they: Strongly agreed (5), Agreed (4), Uncertain (3), Disagreed (2) and, Strongly disagreed (1)

Results and Discussion

Quantitative Data

Table 1 shows pass rates for regular attendees and non-attendees for both modules from 2009 to 2011.

In common with previous single module or single institution studies, regular attendance at SI sessions seems to be partially effective in achieving higher pass rates, however, the numbers of students participating and the difference in pass rates is not significant enough in most cases to draw a conclusion of improved performance due to the sessions attended. Many other potential reasons could be affecting the improved performance such as motivation, educational background and level of achievement to that point.

Table 1. Pass Rates of the SI interventions (\(^1\)This data only includes students from Electrical, Electronic and Computer Engineering, Mechanical Engineering students had separate instruction.)

<table>
<thead>
<tr>
<th>Module and Year</th>
<th>Pass Rate (Regular SI attendees)</th>
<th>Number of regular attendees</th>
<th>Pass Rate (non-attendees)</th>
<th>Number of non-attendees</th>
</tr>
</thead>
<tbody>
<tr>
<td>Systems and Simulation 2009</td>
<td>75.9</td>
<td>29</td>
<td>69.6</td>
<td>136</td>
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<tr>
<td>Control Systems 1 2009(^1)</td>
<td>55.5</td>
<td>13</td>
<td>29.4</td>
<td>25</td>
</tr>
<tr>
<td>Systems and Simulation 2010</td>
<td>42.9</td>
<td>28</td>
<td>38.2</td>
<td>29</td>
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<tr>
<td>Control Systems 1 2010</td>
<td>95.5</td>
<td>22</td>
<td>84.0</td>
<td>114</td>
</tr>
<tr>
<td>Systems and Simulations 2011</td>
<td>68.4</td>
<td>38</td>
<td>62.5</td>
<td>131</td>
</tr>
</tbody>
</table>

The analysis of the academic records of students attending at least one SI session carried out examines the claim that SI assists students to realize their learning potential by transferring skills modeled by the SI leaders. Table two shows the average degree course results obtained pre- and post-SI for the random sample of students.

From the student records, 10 out of the 26 students (38%) in the sample did show an improvement in their marks after attending SI sessions, while 7 of those students passed the
module. This does however mean that 16 students (61%) appear to perform better or equally as well before attending the Systems and Simulation 2010 sessions. From these, it cannot be said that SI has improved the performance of attendees in other modules through transferred skills. Although most students would have already completed significantly higher numbers of modules pre-SI compared to post-SI, there appears to be no correlation to support claims of transfer of skills, suggesting that the only tangible effect of the SI is in completion of the module in which it was taken.

Table 2. Pre- and post-SI average achievements for SI attendees in Systems and Simulation 2010.

<table>
<thead>
<tr>
<th>Student</th>
<th>SI sessions attended</th>
<th>Pre SI average marks</th>
<th>Post SI average marks</th>
<th>Student</th>
<th>SI sessions attended</th>
<th>Pre SI average marks</th>
<th>Post SI average marks</th>
</tr>
</thead>
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</tr>
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<td>50</td>
<td>44</td>
</tr>
<tr>
<td>9</td>
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<td>53</td>
<td>53</td>
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<td>23</td>
<td>4</td>
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<td>72</td>
</tr>
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<td>11</td>
<td>1</td>
<td>57</td>
<td>53</td>
<td>24</td>
<td>4</td>
<td>57</td>
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<td>4</td>
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<td>70</td>
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<tr>
<td>13</td>
<td>4</td>
<td>52</td>
<td>50</td>
<td>26</td>
<td>9</td>
<td>62</td>
<td>71</td>
</tr>
</tbody>
</table>

Qualitative Data
For each of the questions relating to student experience of the SI process, a pie chart has been prepared showing the student responses to the various statements, these are shown in figures 1 through 5.
In Figure 1 it can be seen that students attending SI in 2011 have shown agreement that SI has helped them to better understand the module material. As these questionnaires were conducted prior to the examination, this question merely tested the student perception of the effect of SI which seems to be fairly positive as a method of improving perceived understanding of the module material.

Question 9 deviated from question 8 in that quite a few (30%) students indicated that they were uncertain as to whether or not attending SI sessions for this module would increase their performance. This could be attributed to the fact that the questionnaire was carried out at the end of the semester (after continuous assessment contributions but before the final exam). There is, however, still an overall positive perception that SI has or will help with improved module performance.

Both of these responses echo literature findings that students perceive SI as assisting them in their studies, and believe that it is a useful intervention to enhance academic performance.
Figure 3. Question 10 - SI sessions helped me understand other modules better by using the skills learnt in SI sessions

Question 10 shows a marked difference in how students felt about the statement with 54% (20) of the students indicating that they were uncertain as to whether SI in Systems and Simulations 2011 had any effect with helping them understand their other modules better. While 16% of the students indicated that they felt that SI did not help them understand other modules. The slight positive response overall, does suggest, however, that a proportion of the students attending SI do actually perceive SI as having a skills element as well as assisting in the particular module.

Figure 4. Question 11 – SI Sessions helped me improve my performance in other modules by using the skills learnt in SI sessions

Similar to Figure 3, Figure 4 above indicates that most students (46%) were uncertain about whether SI had improved their performance in other modules by using the skills learnt in Systems and Simulation SI sessions. What is very different from previous results is that the rest of the students were equally divided in their response. Both negative and positive
responses received 27% each. As by this point in time, students had already been assessed a number of times in a variety of modules, this lack of an overall negative or positive feeling indicates once again that although some students may have taken on board the cross-curricular skill development of SI, few are actually using it or believe that it has improved their performance.

The results of the student questionnaire seem to allude to the fact that although students seem to be benefiting from SI in a particular module in so far as being able to pass the module goes, the reasons for their achievement are not necessarily aligned to the stated goals of an SI programme to provide students with skills which can be transferred to other modules studied.

In an attempt to better understand what was happening within the SI sessions two of the SI leaders for Systems and Simulation were interviewed. They were asked open ended questions about what how they perceived SI to assist students, and whether the goals of the SI programme were being achieved. A selection of the pertinent comments made by the leaders follows:

“A lot of students attend physically but not mentally, sort of sit there and expect answers. At the bare minimum they are getting a bit more practice in the module, if they are prepared, they often get a lot more from SI discussions.”

“It might not be achieving the goals in the way they are supposed to but it does work for some students. SI isn’t really suited to this module. But working in groups has seemed to help.”

“I think it works but more as a way to practice and to figure out what happened in the lecture. I sometimes have to teach what was in lectures again.”

“There seems to be a block in students’ heads as how to work and Sys and sim is the first module where they can’t just learn, they have to understand the work and transfer that in to other contexts.”

“SI is working just not in the way it was designed to work or to the degree it should be working. This could possibly be a problem with student buy in, they will accept the help but only in a way they want it.”

“When it comes to realizing that they have to understand something rather than rote learn, well that is very dependent on the student.”

When looking at these statements what becomes clear is that SI is probably not working in exactly the same way as it was intended to. Students seem to be using SI as a way to catch up what they missed in class or as a space where they can practice the problems which they have as tutorial work. It is also clear that what really seems to be a predictor of success are the students themselves. If they are mentally and physically prepared for the SI session and what it aims to do then they will benefit from the sessions both in the present and in the future, however if students merely attend to catch up or fill their time then they will probably gain some benefit in the short term by passing the module through extensive practice, but this will not be long lasting and may not impact on proper understanding of the material covered.

Most of these statements refer to students using the SI sessions as a short term strategy (the motivation being to pass the module rather than the motivation being to foster a deeper understanding of the subject) to achieve a pass in a module that they have either experienced to be difficult, or have perceived to be difficult. This forces us to question whether SI is simply becoming an extension of the actual module, rather than ‘supplemental’ to the module as is posited.

Conclusions

At present, the conclusions that can be made are that:
• Students who attended regular supplemental instruction sessions in the modules studied do exhibit more likelihood of passing the modules, however, this is not proven to be statistically significant.

• Students who attended SI view it as a positive method for improving their understanding of module content

• Both the records of students who attended SI sessions and their responses to the survey indicate that SI is not achieving its stated goal of developing transferrable study skills which influence continued improved academic performance.

Recommendations
From this initial study, it is difficult to draw concrete conclusions due to the small amount of data available. The study does, however, suggest that further research into this aspect of SI would be of interest.

Future work will include further surveys of students across all years of their degree programmes and in a range of modules which offer SI. It is hoped that the expansion of the number of participants could allow the researchers to determine whether there is a definite perceived benefit of SI beyond simply passing a module, and whether or not this perception could possibly be linked to year of study.

As this research was carried out using a set of third level student marks (ie. three quarters of the way through their degree programme), students who are taking SI for the first time at this level are potentially using it purely as a ‘crutch’ to help them through a difficult module, students who attend first and second year SI may display a different viewpoint (again, this needs investigation) which may ultimately back up the claims made in the literature regarding skills development.

References


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Knowledge Typologies and the Engineering Curriculum at the Nelson Mandela Metropolitan University

Patsy Paxton¹ and Sarel Schoombie²

¹Higher education Consultant, Nelson Mandela Metropolitan University, South Africa; ²School of Engineering, Nelson Mandela Metropolitan University

¹p.a.paxton@gmail.com, ²sarel.schoombie@nmmu.ac.za

Abstract

Using the explanatory conceptual framework developed as part of the South Africa Norway Tertiary Education Development (SANTED) Project, the Mechanical Engineering and Mechatronic qualifications at the Nelson Mandela Metropolitan University (NMMU) were analysed in order to distinguish between different forms of knowledge within the curricula and to ascertain how far the actual curricula of these specific degree and diploma programmes demonstrate appropriate differences in their curricular logics.

Drawing on Gamble’s conceptual distinction, a knowledge typology was devised which distinguishes between ‘conceptual knowledge’ and ‘procedural (or contextual) knowledge’, and for each of these types further distinctions between principled and procedural were made, thereby creating a five-part knowledge typology: conceptual knowledge; proceduralised conceptual knowledge with an overarching conceptual coherence; proceduralised conceptual knowledge with an overarching contextual coherence; procedural knowledge; and principled procedural knowledge. Therefore both conceptual and procedural (contextual) knowledge can be principled but with an important difference: in principled procedural knowledge the principles emerge from the procedures themselves; they emerge from the codification of practice. In proceduralised conceptual knowledge, the principles emerge from the conceptual domain; from the theory.

From this knowledge typology the conceptual framework accounts for what happens when these different kinds of knowledge are drawn on as resources for curriculum, or re-contextualised into curriculum. Muller (2008) distinguishes between different curriculum logics, that is, curricula which have conceptual coherence and those that have contextual coherence.

Further analyses, using Umalusi’s taxonomy (adapted from Krathwohl 2002 in Gamble 2009) were undertaken to identify different levels of cognitive complexity. This analysis enables a distinction to be made between, for example, a conceptually oriented module which simply required recall (low complexity), explanation (medium complexity) or application of concepts (high complexity).

The unit of analysis was the module, and for each programme module data was collected (for example, module outlines, assessment documentation and lecture notes).

Introduction

The academic qualifications of the Nelson Mandela Metropolitan University (NMMU) were previously separated formally into a university and a technikon stream with different foci in terms of the provision of the more formative education typically associated with university qualifications and the more vocational education associated with technikon qualifications.
The distinct nature of the separate qualification pathways meant that opportunities for articulation were effected on mainly an ad-hoc nature and were not based on a systematic understanding of the knowledge properties of different qualification types. The overarching objective of the SANTED Project was to assist the NMMU in the development of proposals for consolidated qualification structures in a range of academic disciplines and fields where qualifications that previously belonged to the separate streams have been brought together. It was envisaged that the Project would assist the NMMU in the development of a consolidated and coherent programme and qualification mix which accommodates different qualification types in a manner that respects and strengthens their knowledge properties and offers students optimal opportunities for access, success and articulation.

**Contextual background of the NMMU**

The NMMU draws 70% of its students from the Eastern Cape which historically has had the lowest matriculation pass rate in the country (NMMU Self Evaluation Report 2008). Accordingly it is essential that the NMMU has mechanisms in place to both increase access to higher education studies and to support students from educationally disadvantaged backgrounds during their studies. The NMMU has fortunately been able to build on the foundations laid by its merging institutions in this regard and the issues of access and student development are accorded a high priority.

The creation of multiple articulation routes has the potential effect of broadening access to programmes, especially programmes on a higher level of the Higher Education Qualification Framework (HEQF). However, to achieve this effect, it is critical to explore the conditions under which articulation should be possible, so that a certain standard of performance at one level of the programme in terms of academic performance as well as students’ familiarity with specific types of knowledge and the complexity with which knowledge is contextualised in the curriculum, may facilitate access to a programme at the next level. While work on the NMMU SANTED case studies has avoided the complex and often controversial issue of broadening the variety of admissions criteria to include both academic and non-academic criteria (such as work experience), its focus has included the consideration of responsible multiple entry routes which could possibly be created through articulation possibilities between programmes within a discipline and even between disciplines. The need to formalise articulation arrangements between programmes and programme-types and to align qualifications with different knowledge properties and levels of cognitive complexity to the HEQF, were two of the major focus areas of the SANTED Project.

**Conceptual framework for describing knowledge types, curriculum logic and methodology**

The starting point for the development of the conceptual framework informing the analysis was the knowledge continuum which Muller (2008) sets out in his classification of occupational fields, knowledge and induction as in Table 1 as follows:
Table 1. Muller’s (2008) knowledge continuum

<table>
<thead>
<tr>
<th></th>
<th>ROUTE 4 Conceptually relevant</th>
<th>ROUTE 3 Contextually relevant</th>
<th>ROUTE 2 Conceptually relevant</th>
<th>ROUTE 1 Conceptually relevant</th>
</tr>
</thead>
<tbody>
<tr>
<td>Labour Market</td>
<td>Particular / specific occupations</td>
<td>General Occupations</td>
<td>Traditional and some 4th generation professions</td>
<td>Academia; 4th generation professions</td>
</tr>
<tr>
<td>Knowledge</td>
<td>Largely practical knowledge</td>
<td>Practical knowledge &amp; some applied theory</td>
<td>Applied theory &amp; practical experience</td>
<td>Largely theoretical progression of the discipline</td>
</tr>
<tr>
<td>Induction</td>
<td>On-the-job-training, some apprenticeship</td>
<td>Apprenticeship</td>
<td>External internship (e.g. housemanship)</td>
<td>Internal internship (e.g. postdoctoral work, tenure)</td>
</tr>
<tr>
<td>Regulation</td>
<td>Moderate to weak sectoral regulation (e.g. hairdresser’s practical test)</td>
<td>Moderate sectoral regulation (e.g. trade tests)</td>
<td>Strong sectoral regulation (e.g. accreditation requirements; board exams)</td>
<td>Moderate to strong disciplinary regulation (peer review)</td>
</tr>
</tbody>
</table>

Muller argues that within each occupational group, there is differentiation in the knowledge base ranging from practical knowledge in the occupation pathway to theoretical knowledge in the academic pathway and various combinations in-between. It is the combinations in-between that offer the biggest challenge for the comprehensive universities and require more fine-grained distinctions. Conceptualising distinctions in knowledge along the qualification pathways with a particular focus on the occupational / professional end requires an understanding of practical, context-specific knowledge and for this the work of Gamble was used (2009).

Building on and extending Bernstein’s (2000) theorisation of knowledge, Gamble’s model (2009) distinguishes between general (context-independent) and particular (context-dependent) knowledge. The former – general knowledge – can be divided into both principled and procedural knowledge. In other words, ‘pure’ theory and ‘applied’ theory. Gamble argues that the same principled / procedural division is also to be found in particular knowledge. In other words, there are two kinds of practical knowledge, that of the everyday and that which is principled. Her research into crafts shows that while the cabinet-maker’s knowledge is tacit, it is deeply principled. It relies on an understanding of the relationships
between parts and whole, and a grasping of the ‘essential principles of arrangement’ (Gamble 2009: 196).

Drawing on Gamble’s conceptual distinction, a knowledge typology was devised which distinguishes between ‘conceptual knowledge’ and ‘procedural (or contextual) knowledge’ and for each of these types further distinctions between principled and procedural were made, thus creating a four-part knowledge typology: conceptual knowledge, proceduralised conceptual knowledge, procedural knowledge and principled procedural knowledge. Thus both conceptual and procedural (or contextual) knowledge can be principled but with an important difference: in principled procedural knowledge the principles emerge from the procedures themselves; they emerge from the codification of practice. In proceduralised conceptual knowledge, the principles emerge from the conceptual domain; from the theory. These are distinctive forms of knowledge and do not lead from one to the other; that is, they are not hierarchical. Procedural knowledge does not lead to conceptual knowledge and conceptual knowledge does not lead to procedural knowledge. This becomes a fundamental point when the issues of curriculum and articulation possibilities are addressed.

From this knowledge typology the conceptual framework accounts for what happens when these different kinds of knowledge are drawn on as resources for curriculum, or re-contextualised into curriculum. As already noted, Muller (2008) distinguishes between different curriculum logics, that is, curricula which have conceptual coherence and those that have contextual coherence. Conceptual coherence refers to curricula where the logic of the curriculum comes from the conceptual building blocks of the discipline. Contextual coherence refers to curricula where the logic comes from the external purposes of the curriculum, such as professional and occupational requirements. These logics are better thought of as a continuum since both are always present – curricula which cohere around a contextual logic are not devoid of conceptual knowledge, and curricula which cohere conceptually are not devoid of contextual concerns.

The key issue is what is the dominant logic? This dominant logic will distinguish occupational and professional programmes (i.e. contextually-oriented) from general-formative programmes (i.e. conceptually-oriented). Depending on whether it is predominantly conceptually- or contextually-oriented, different kinds of knowledge will be re-contextualised in different ways.

Early analyses of the module data in several SANTED case studies, including Journalism and Media Studies, when the distinction was made between modules which are on the one hand conceptually-oriented and those which are contextually-oriented, led to a further extension of the four-part knowledge typology into a five-part typology as follows:

With respect to the contextual-orientation, there are three possibilities: pure procedural knowledge (C1); principled procedural knowledge (C2); and proceduralized conceptual knowledge with an overarching contextual logic or coherence (C3).

With respect to the conceptual-orientation, there are two possibilities: proceduralized conceptual knowledge with an overarching conceptual logic or coherence (C4), and pure conceptual knowledge (pure theory) (C5).

Also emerging from the preliminary analyses was the need to specify different levels of cognitive complexity. This was undertaken using Umalusi’s taxonomy (adapted from Krathwohl 2002 in Gamble 2009) (See Table 2). The analysis of cognitive complexity enabled a distinction to be made between, for example, a conceptually oriented module which
simply required recall (low complexity), explanation (medium complexity) or application of concepts (high complexity).

Table 2. Levels of Cognitive Demand / Complexity

<table>
<thead>
<tr>
<th>Category</th>
<th>Level</th>
<th>Descriptions</th>
</tr>
</thead>
<tbody>
<tr>
<td>LOW Factual Recall / Rote</td>
<td>1: Simple</td>
<td>Simple factual recall</td>
</tr>
<tr>
<td></td>
<td>2: Medium</td>
<td>Recall complex content</td>
</tr>
<tr>
<td>MEDIUM Understanding of concept / principle; application; analysis</td>
<td>1: Simple</td>
<td>Simple relationships; simple explanations</td>
</tr>
<tr>
<td></td>
<td>2: Medium</td>
<td>More complex relationships or explanations; counter-intuitive relationships; qualitative proportional reasoning</td>
</tr>
<tr>
<td></td>
<td>3: Challenging</td>
<td>Identify principles which apply in a well-defined context</td>
</tr>
<tr>
<td>HIGH Creativity / critical &amp; analytical skills / application &amp; integration of all skills</td>
<td>1: Simple</td>
<td>Simple procedure; plug into formula with only one unknown; no extraneous information; known or practised content</td>
</tr>
<tr>
<td></td>
<td>2: Medium</td>
<td>Integration of all skills; marketable product; complex problems involving insight and logic leaps; formulating new equations (using all unknowns); problem-solving in a novel context</td>
</tr>
<tr>
<td></td>
<td>3: Challenging</td>
<td>Integration of all skills; marketable product; complex problems involving insight and logic leaps; formulating new equations (using all unknowns); problem-solving in a novel context</td>
</tr>
</tbody>
</table>

It is important to note that cognitive complexity is not coterminous with curriculum type. That is, it is possible to have C2 and C3 curricula at a high level of cognitive demand.

Data Analysis

These research questions were taken to the analysis of the National Diploma / BTech: Mechanical Engineering and the BEng (Mechatronics) in order to try to understand what types of knowledge constitute each of the three qualifications. The unit of analysis was the module. For each programme module data was collected (for example, module outlines, assessment documentation, lecture notes, and power point slides).

For each module the following questions were asked:

What is the dominant logic of the module curriculum? Is it predominantly conceptual or contextual logic?

What type of knowledge dominates in the module? Is it proceduralised knowledge or principled proceduralised knowledge? Is it conceptual knowledge or proceduralised conceptual knowledge?
While the researcher undertook an initial coding, final decisions on coding were confirmed after discussions with the academic staff who teach the modules in these programmes.

B Eng (Mechatronics)

<table>
<thead>
<tr>
<th>Year</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yr4</td>
<td>28%</td>
<td>63%</td>
<td>9%</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>H</td>
<td>H</td>
</tr>
<tr>
<td>Yr3</td>
<td></td>
<td>C3</td>
<td>C4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>89%</td>
<td>11%</td>
</tr>
<tr>
<td></td>
<td>H</td>
<td></td>
<td>H</td>
</tr>
<tr>
<td>Yr2</td>
<td>C3</td>
<td>C4</td>
<td>C5</td>
</tr>
<tr>
<td></td>
<td>58%</td>
<td>14%</td>
<td>28%</td>
</tr>
<tr>
<td></td>
<td>M-H</td>
<td>M-H</td>
<td>M-H</td>
</tr>
<tr>
<td>Yr1</td>
<td>C2</td>
<td>C3</td>
<td>C4</td>
</tr>
<tr>
<td></td>
<td>12%</td>
<td>32%</td>
<td>24%</td>
</tr>
<tr>
<td></td>
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</table>

B Tech (Mechanical Engineering)

<table>
<thead>
<tr>
<th>Year</th>
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<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yr3</td>
<td>87%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>H</td>
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</table>

Nat Dip (Mechanical Engineering)

<table>
<thead>
<tr>
<th>Year</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yr3</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>L-M</td>
<td></td>
</tr>
<tr>
<td>Yr2</td>
<td>C2</td>
<td>C3</td>
</tr>
<tr>
<td></td>
<td>4%</td>
<td>64%</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>M-H</td>
</tr>
<tr>
<td>Yr1</td>
<td>C2</td>
<td>C3</td>
</tr>
<tr>
<td></td>
<td>30%</td>
<td>44%</td>
</tr>
<tr>
<td></td>
<td>L-M</td>
<td>M</td>
</tr>
</tbody>
</table>

**Figure 1.** National Diploma / BTech: Mechanical Engineering & BEng (Mechatronics): selection and sequencing of knowledge and curriculum type
Using these analytical tools, each module for the National Diploma / BTech: Mechanical Engineering and the BEng (Mechatronics) was coded for curriculum type (C1-5) and for cognitive complexity (low, medium or high). Across each year (Years 1, 2 and 3) modules were aggregated by curriculum type and cognitive complexity and weighted by credits, e.g. all the credits for the modules coded C2 within a particular year were added and divided by the total credits for the year (usually 120) to arrive at percentage of curriculum type per year, for example, 44% of credits in Year 1 of the National Diploma: Mechanical Engineering was coded C3. Cognitive complexity was recorded according to whatever level (L, M & H) was most dominant, for example C3 H. If there was relatively even allocation, both levels were recorded, for example C4 M-H.

### Curriculum logic & knowledge type

<table>
<thead>
<tr>
<th>Curriculum logic &amp; knowledge type</th>
<th>Cognitive complexity</th>
</tr>
</thead>
<tbody>
<tr>
<td>C2 Contextual coherence with principled procedural knowledge</td>
<td>Low</td>
</tr>
<tr>
<td>C3 Contextual coherence with proceduralized conceptual knowledge</td>
<td>Medium</td>
</tr>
<tr>
<td>C4 Conceptual coherence with proceduralized conceptual knowledge</td>
<td>High</td>
</tr>
<tr>
<td>C5 Conceptual coherence with conceptual knowledge</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 2.** Legend for combined matrix of knowledge typology cognitive complexity

### Findings

The findings for the National Diploma / BTech: Mechanical Engineering and the BEng (Mechatronics) are presented in a diagram of what knowledge has been selected and how this knowledge has been sequenced for progression (Figure 1, above). ‘Progression’ refers to the extent to which there is development of complexity with respect to a particular curriculum type across Years 1 to 3 of the programme, for example from C2 Low in Year 1 to C2 High in Year 3. The findings are presented in three parts: selection of knowledge and curriculum type, sequence of knowledge within the curriculum, and the implications of selection and sequence for progression and articulation.

### Selection of knowledge and curriculum type

In the National Diploma: Mechanical Engineering, the overall curriculum logic is contextual. There is a strong core of proceduralized conceptual knowledge (with overarching contextual coherence) (C3) as follows: 44% in Year 1; 64% in Year 2; 100% in Year 3. A small proportion of proceduralized conceptual knowledge (with overarching conceptual coherence) (C4) can be seen as follows: 26% in Year 1; 32%, while a low proportion of principled procedural knowledge (C2) occurs as follows: 30% in Year 1; 4% in Year 2.

In the BTech: Mechanical Engineering, the overall curriculum logic is contextual. There is a strong core of proceduralised conceptual knowledge (with overarching contextual coherence) (C3): 87%, and a small proportion of proceduralized conceptual knowledge (with overarching conceptual coherence) (C4): 13%.

In the BEng (Mechatronics), the overall curriculum logic is contextual. A strong core of proceduralised conceptual knowledge (with overarching contextual coherence) (C3) is found as follows: 32% in Year 1; 58% in Year 2; 89% in Year 3; 63% in Year 4. A decreasing proportion of proceduralized conceptual knowledge (with overarching conceptual coherence) (C4) is seen as follows: 24% in Year 1; 14% in Year 2; 11% in Year 3; 9% in Year 4, while a
very low proportion of principled procedural knowledge (C2) exists as follows: 12% in Year 1; nothing in Years 2 and 3; 28% in Year 4.

**Sequencing of knowledge within the curriculum**

With respect to C2, C3 and C4 knowledge in the National Diploma: Mechanical Engineering, there is a slight increase in cognitive complexity from Year 1 to Year 2. However in the case of C3, this then diminishes in Year 3

BTEch: Mechanical Engineering, on the other hand, shows a high cognitive challenge in both C3 and C4.

Focussing on the BEng (Mechatronics), with respect to C2 knowledge, there is no increase in cognitive complexity from Year 1 to Year 4 (the two years where this knowledge appears), while regarding C3 knowledge, there is an increase in cognitive complexity from Year 1 through to Year 4. With respect to C4 knowledge, there is an increase in cognitive complexity from Year 1 through to Year 4, and with respect to C5, there is a slight increase in cognitive complexity from Year 1 to Year 2.

**Implications of selection and sequence for progression and articulation**

A number of interesting implications for progression and articulation can be drawn from the analysis of the Mechanical Engineering and Mechatronics case study:

The National Diploma: Mechanical Engineering appears to have a clear core of C3 knowledge and a medium to high level of cognitive complexity. However the large proportion of C3 knowledge at a low to medium level at Year 3 is a concern. This suggests that students who progress from the National Diploma to the BTEch, with high cognitive complexity throughout, may experience difficulties.

With respect to the BEng (Mechatronics), like the National Diploma / BTEch: Mechanical Engineering, the main progression appears to also be in C3 knowledge. Of note is that the cognitive complexity of the C3 in the Degree is similar to that of the BTEch, and both are higher than that of the Diploma.

Articulation from the Diploma (Mechanical Engineering) into the BEng (Mechatronics) will be problematic, given the high percentage of C5 knowledge in Years 1 & 2 of the BEng (Mechatronics).

In terms of articulation from the Diploma to the BEng, the diploma student may be well-prepared with respect to C3 and C4 knowledge but the C5 knowledge requirements of the degree in Year 1 may pose a stumbling block.

The high proportion of C4 (proceduralized conceptual) knowledge in Year 1 of the Diploma & high proportion of C4 & C5 (conceptual) knowledge of the Degree could mean that students who have been ill prepared by the school system could be academically challenged.

Finally, staff members justified the logic of the Diploma and the Degree on the basis of the requirements of the professional Engineering body, ECSA. From the point of view of the professional body, the Diploma and the Degree produce very different kinds of graduates for different kinds of employment in the Engineering industry.

**Conclusion**

This conceptual framework provides a useful language for academic staff to review their existing curricula on the basis of a better understanding of the differentiation between their
diplomas and degrees. Further refinements of the concepts and the methods will be necessary. The analysis of sequence and progression using Bloom’s adapted levels of cognitive complexity needs to be reviewed. Further research needs to be conducted to better understand the concept-procedure relationship in C3 and C4.

Finally, the analysis to date has also been confined to the intended curriculum, not the enacted curriculum, and the high drop-out rates in some programmes suggests that recurriculation initiatives will need greater understanding of what is happening in the enacted curriculum. Furthermore, this analysis has not factored in the pedagogies used to facilitate the movement from the theoretical to the practical. This is clearly an important area that requires consideration.

References


NMMU Self Evaluation Report (2008). Figure 2.11 (Section 2.7).


Acknowledgements

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Barriers to Progression: An Exploratory Study of an Access Programme for Engineering

Jon Pocock¹, Annah Bengesai² and Mogasuri Moodley³
ASAP (The Academic Support and Advancement Programme), Faculty of Engineering,
University of KwaZulu-Natal, Durban, South Africa
¹Pocockj@ukzn.ac.za, ²Bengesai@ukzn.ac.za, ³Moodleym5@ukzn.ac.za

Abstract

This article examines modules that act as barriers to progression for students who come into engineering through an access programme. These modules are examined using Bloom’s taxonomy of the cognitive domain to ascertain the cognitive levels at which students face challenges. The findings indicate that while UNITE students perform better in modules that require recall of facts and understanding, they generally struggle with modules that require higher order thinking skills such as application, analysis, synthesis and evaluation. It is recommended that UNITE incorporate all levels of the taxonomy in its curriculum if it is to provide the opportunity to develop the cognitive skills that will enable its students to participate effectively in the mainstream engineering modules.

Introduction

‘Who does not succeed in engineering[?] What can one tell from the retention rate?’(Jawitz and Scott, 1997).

These questions were asked by Jawitz and Scott in (1997) in a study at the University of Cape Town. Since then, a number of reports have attempted to address these questions (Department of Science and Technology, DST, 2009; Du Toit and Roodt, 2009; Scott, Yeld and Hendry, 2007). Most of these reports have used cultural-historical reasons to explain attrition; hence they have come to the conclusion that attrition rates are severe for the ‘educationally disadvantaged’ students (Letseka, Breier and Visser, 2009; Letseka and Maile, 2008). In fact, Cosser and Letseka (2009) suggest that student attrition is a perennial theme in South Africa. More specifically in engineering Du Toit and Roodt (2009) reveal that only 60% of students that entered into engineering education between 1999 and 2005, graduated (after six years in the system). This is also echoed by Case (2006) who posits that only a marginal number of engineers graduate from South African Higher Education institutions. Notwithstanding the fact that access to engineering education has improved for students (see for instance Altman and Lee, 2004), the discourse on retention and drop out suggest that in terms of progression, ‘educationally disadvantaged’ students lag behind their counterparts from the more advantaged contexts. This is largely attributed to the legacy of Bantu education, which did not equip these students with the necessary competencies needed for success in higher education (Scott et al., 2007).

In response to ‘educational disadvantage’ (institutions, government) have come up with ways to curb attrition rates. At the University of KwaZulu-Natal, an academic programme was put in place, (University of KwaZulu-Natal Intensive Tuition for Engineers - UNITE) to provide both physical and epistemological access in engineering education to students from disadvantaged backgrounds. More recently, in 2006, the Faculty of Engineering at UKZN received a grant from the Department of Education to improve throughput in Science, Engineering and Technology courses. This has resulted in the establishment of the Academic
Support and Advancement Programme (ASAP), a community of practice which focuses on improving throughput and retention rates in the faculty. Yet, in spite of such endeavors, there is concern among stakeholders that performance among students from previously disadvantaged educational backgrounds still falls behind. The study on which this article is focused was commissioned by the UKZN’s Faculty of Engineering as a result of such concerns. More specifically, this concern is expressed in terms of a gap between success in UNITE and progression in the mainstream. Hence, despite achieving early on, it is believed that UNITE students do not sustain their achievements and consequently drop out prior to completion of the degree. It follows then, that it is necessary to determine the current progression rates of UNITE students in the mainstream, leading to the first research question:

a) What is the progression rate of UNITE students currently in mainstream?

Whilst acknowledging the cultural-historical views cited in most studies as possible explanations for underachievement, we believe more insights can also be gained from identifying and examining the nature of the modules which act as stumbling blocks for these students. Taking this position therefore, led us to the second and third research question:

b) Which mainstream modules act as barriers for UNITE students?

c) What are the cognitive demands of these modules?

We are not unaware of the fact that reasons for retention, progression and attrition operate at the level of the individual student (agency), institution (educational provision) and supra-institution (such as financial and socio-economic, see Muller and Prinsloo, 2007). Nonetheless, we believe efforts to explain attrition have focused mainly on the individual and supra-institutional factors, efforts which potentially result in programmes which intend to change students rather than the systems in which they participate in learning (Gutierrez, Morales and Martinez, 2009). Boughey (2009) succinctly captures this when she says;

In spite of this tendency to draw on context to explain poor learning and what, in liberal terms, is constructed as ‘disadvantage’ or ‘underpreparedness’, what remains is essentially an autonomous model which locates capacity (including will) to learn within individual (p. 2).

Essentially, whilst these conceptualizations of attrition at the individual and societal level succeed in making students’ problems visible, they do not problematise the institutional system and its pedagogic practice. Hence, they locate the deficit in the individual student, thereby letting the institutional systems off the hook (Thesen and van Pletzen, 2006). We believe there is a clear distinction in the reasons for slow progression; and propose to focus on one of the reasons which seem to be neglected in the literature, that is the modules.

There are five main sections to this article. The first section provides the context for the study. The second section sets out the theoretical constructs informing this study. This is followed by the methodology section. In the fourth section we present the findings. The final section is the discussion of these findings in relation to the theoretical framework and the literature reviewed.

Context

At UKZN, an access programme for engineering, UNITE, has been developed to provide access to students who have been educationally disadvantaged and identified as having the potential to excel academically. (http://mecheng.ukzn.ac.za/UNITE.aspx). To gain access into UNITE; students must meet the minimum entrance criteria (at least a ‘D’ symbol in mathematics, physical science and English, Faculty of Engineering Handbook, 2011). UNITE
seeks to develop in their students the skills necessary for academic excellence and successful completion of the engineering degree.

The UNITE curriculum is designed such that students attain full credits in first year modules: Engineering Drawing and Mathematics. Subjects that students are required to take that are non-credit-bearing are Physics, Chemistry, Mechanics and Communication Skills. Students gain exposure to the practice of engineering through site visits, lectures from professional engineers as well projects that are run within UNITE.

The approach to teaching and learning at UNITE favours an interactive learning environment with the purpose of enhancing learning, developing the life skills necessary for successful university study and successful graduation as an engineer. Successful students in the UNITE programme are admitted into the Faculty of Engineering.

Theoretical framework

Our exploration of the barriers to progression for the UNITE students is in effect, an exploration of learning. As such, we draw our theoretical constructs from learning theories. Learning is a process which involves various aspects such as cognitive, affective, social and psychomotor. This understanding has led to a number of learning theories which privilege some of these aspects for example; cognitivism, behaviorism and constructivism (see Bigge and Shermis, 1992) and situated learning/social theories (see Lave and Wenger, 1991). This indicates that there is no consensus as to how people learn. Whilst accepting the insights drawn from all these learning theories, in this article, we are guided most generally by Bloom’s taxonomy of learning in the cognitive domain.

Bloom and his compatriots classified cognitive operations that people engage in when they learn into six levels of increasing complexity, from knowledge, which requires simple recall of facts to evaluation which requires judgment (Bloom, Engelhart, Furst, Hill and Krathwohl, 1956) as shown in Figure 1 below.

These levels are taxonomic because progression to one level is dependent on success at the preceding one. Although the taxonomy was initially designed as an assessment tool, it has had wider application in the analysis of course objectives or the entire curricula (McGee 2003). Undoubtedly, curricula in higher education are designed around a similar cumulative framework, which progresses from simple to complex as students move from one level to another. Thus in this study, we anticipate finding modules requiring complex cognitive

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**Figure 1.** Bloom’s taxonomy of the cognitive domain

(\url{http://www.uvm.edu/~cdisorda/blooms.html} accessed 3.25pm 3rd June 2011)
operations as the barriers to progression for UNITE students in our sample. Blooms’ taxonomy therefore, provides us with both a methodological and analytical tool for describing and classifying the cognitive demands of engineering modules.

Blooms’ taxonomy of the cognitive domain has been adapted by Anderson and Krathwohl (2001). Changes in the new taxonomy include a shift from nouns to verbs (for instance, knowledge domain to remembering, application to applying), the inversion of levels 5 and 6 (level 5 synthesis in the original taxonomy is now level 6 and has also been renamed creating in the revised version while level 6 evaluation has been repositioned to level 5). Another difference is the link between the taxonomy and different levels of knowledge (factual, conceptual, procedural and metacognitive). While these revisions are informative, the order of levels 5 and 6 is debatable and depends on the way knowledge is structured in a discipline. For the purposes of this study, we follow the original version of Bloom’s taxonomy because it is relevant to the way modules in the faculty of engineering are structured. In engineering education, the highest skill level is evaluation, and for this to take place, one needs to have understood, analysed and applied and synthesized material. Further explanation of these levels is offered in the methodology section to follow.

**Methodology**

The study on which this article is based sought to:

- Determine the progression rates for the UNITE students once they enter mainstream
- Identify and explore the modules that were barriers to progression for the UNITE students.

Each of the methods required the use of student records, and students’ names were omitted to ensure confidentiality. This section describes the methods used to generate data that would provide answers to the research questions. To determine the progression rates for UNITE students once they enter mainstream, secondary data was drawn from the student database at the university. Data was only collected for students who completed the UNITE programme and entered the mainstream, as those who do not pass are not admitted to the faculty. The completion rate from UNITE was not considered, as the purpose of the study was to determine how those who entered the mainstream coped with their degree studies. This included cohort data on students entering UNITE from 2003 to 2009. This data was also used to identify modules that were barriers to progression. Although the failure of any module is a barrier to normal progression within the Faculty, in many cases, subsequent modules may be attempted when a student achieves a mark between 40%-49% in the final module assessment). This allows progress in other modules whilst the failed module is repeated. To account for this, in this study modules failed at below 40% at the first attempt were regarded as barriers to progression. The modules were grouped into specific subject areas: Mathematics and Science, Engineering Science, Design, Computer Programming and Technical Communication.

In this analysis, records of students who had entered the mainstream from 2004-2007 (that is, UNITE entry in 2003-2006) were re-examined and any modules failed at the first attempt (less than 40%) were assigned a taxonomical level from the module requirements. The levels used were those from the taxonomy of learning domains formulated by Bloom and co-workers (Bloom et al., 1956) as shown in Figure 1. Each of the levels of cognitive skill was assigned a value as follows: Knowledge = 1, Comprehension = 2, Application = 3, Analysis = 4, Synthesis = 5. Level 6 was omitted as the handbook indicates that high order evaluation (or judgment) as described in the original taxonomy is seldom required within undergraduate
engineering modules. Although evaluation may be used to an extent in final year project work, (level 6 in the original taxonomy), judgments made tend to be by the academic co-ordinators rather than the students whilst assessing the project work. Capstone modules such as design and lab project work would generally require synthesis of materials from throughout the programme (that is, a level 5 at most). Using descriptions within the handbook, modules were in this way located as for example 2-3 (that is, requiring an amount of application along with demonstration of understanding of concepts), an example is given in Appendix A. Although the module descriptions in the handbook describe the requirements of that module using terms which can be linked to the taxonomy, it is not possible to ascertain for each module whether the assessments within the specific module relate identically to the descriptors. Where possible (particularly the Chemical Engineering modules), comparisons were made with levels required within examinations and other assessments (projects etc.) within the last year of teaching and showed high correlation with the descriptions.

For each student record, a single ‘cognitive barrier’ level was calculated from the average cognitive levels of barrier modules (for example, if a student failed only modules with level indicators of 3-4, the cognitive barrier is taken as occurring at 3.5+ i.e. higher levels of application, lower levels of analysis i.e. the border of application and analysis). These cognitive barriers can then be used to suggest areas where the UNITE programme could potentially introduce augmentation to exercise their cohorts in higher order cognition.

Findings

Progression rates for UNITE students in mainstream

Table 1 shows the overall analysis over the period 2003-2010 (NB, students begin mainstream studies a year later and graduate in a minimum 5 years).

**Table 1**: Whereabouts of UNITE students who entered the mainstream degree programmes from 2004-2010 (data updated at April 2011)

<table>
<thead>
<tr>
<th>Year Started UNITE</th>
<th>2003</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>2008</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grad in 5 yrs</td>
<td>2</td>
<td>8</td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grad in 6 yrs</td>
<td>2</td>
<td>7</td>
<td>5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Grad in 7+ yrs</td>
<td>3</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Excluded/Dropped Out</td>
<td>14</td>
<td>12</td>
<td>24</td>
<td>8</td>
<td>10</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>Still in System</td>
<td>2</td>
<td>0</td>
<td>6</td>
<td>13</td>
<td>21</td>
<td>38</td>
<td>29</td>
</tr>
<tr>
<td>TOTAL</td>
<td>23</td>
<td>27</td>
<td>36</td>
<td>24</td>
<td>31</td>
<td>39</td>
<td>29</td>
</tr>
</tbody>
</table>

The drop out and exclusion rates for 2008 and 2009 are of a similar order to both those for the Faculty and those found in literature. The more worrying feature is the time taken to graduate for many of the students. For example, those who started UNITE in 2003 should have completed their degrees by the end of 2007; however, two of them were still registered undergraduates in 2010.
Subject areas as barriers to progress

Table 2. Subject Areas as barriers to progression for all students from the UNITE programme entering mainstream from 2004-2010

<table>
<thead>
<tr>
<th>Subject Area</th>
<th>TOTAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maths and Science</td>
<td>86</td>
</tr>
<tr>
<td>Engineering Science</td>
<td>41</td>
</tr>
<tr>
<td>Design</td>
<td>65</td>
</tr>
<tr>
<td>Computer Programming</td>
<td>35</td>
</tr>
<tr>
<td>Technical Communication</td>
<td>22</td>
</tr>
<tr>
<td>Records Checked</td>
<td>197</td>
</tr>
</tbody>
</table>

These totals are the number of failed modules from all 197 student records grouped according to subject area, for example, of the 197 students, there were fails at less than 40% in a total of 86 Maths and Science modules.

Taxonomical Levels of Barriers to Progress

For simpler comparison to the taxonomical levels acting as barriers to progress, each cohort of students has been plotted on a representation of Bloom’s taxonomy in the cognitive domain (Figures 2 to 5). The boxes represent the number of students who experienced difficulty at the various levels, the highest box (on the border of analysis and synthesis) represents a cognitive breakthrough into the higher level (i.e. ability in synthesis, level 5) which would be required in capstone project work required to complete a degree. In other words, numbers in the blue boxes represent graduated students from the cohort.
Discussion

The results suggest that the UNITE students are getting caught up in the modules that require higher levels of cognitive demand. From the 2003 to 2006 cohorts (those that could have completed) there has been a 53% leaving without graduating rate to date, with only a 28% completion rate. These figures are not far off from those reported in the literature (see for instance Du Toit and Roodt, 2009 who place the drop out rate at 60%). The completion rate figure can only rise to 47% should those students remaining in the University graduate.

The point at which students start to leave is also of note here. The 2008 and 2009 cohorts have only had one student leave after one and two years of mainstream study to date. This lower than average loss (the mainstream leaving rate in both years was above 10% (Pocock, 2010) is also apparent in the other cohorts where the maximum first year of mainstream leaving is 9% (from the 2005 cohort) and across the entire period under 3% of students left after a year in the mainstream. After two years of registration, the UNITE cohorts from 2003-2008 less than 15% of students had left the Faculty. The data shows that the cohorts are thus able to progress in first and second year of study potentially at a higher rate than they do in the subsequent years. Beyond this point there seems to be a high rate of students leaving without graduating, and a low completion rate. This could be explained in terms of the taxonomical analysis (in Figures 2 to 5).

The subject area analysis carried out fits the registration data well, but does not point to any specific modules which form barriers to progression for the UNITE students. Actual modules which were failed varied from student to student (over eighty different modules were identified as barriers across the academic records of the students). The grouping of the modules suggests that the Mathematics and Science modules, and the Engineering Science modules are more likely to be found problematic in the later years, however, as these form the bulk of any degree programme, little can be discerned from the data. The taxonomical analysis provides a more focussed examination of the difficulties encountered through distilling the modules into categories based upon the Bloom’s cognitive levels required to successfully complete them. The entry point to mainstream study would require in the main competency at the cognitive levels of understanding (level 2) with some high school subjects requiring an amount of application (level 3). The UNITE programme provides some material at level 2-3 (for example mainstream Mathematics) and augments this and the basic sciences (generally again at level 2-3). First level studies in the mainstream require a level 2-3 (ie.
some application) in the main, there is also some building of the knowledge base (level1-2) in areas such as Chemistry. Second year modules would generally be at levels ranging from understanding to analysis (2-4) with application contained in most modules. Further engineering subjects are grounded in application and analysis (3-4) and capstone subjects in synthesis (5). For the 2003 cohort, application of material and analysis of the outcomes seems to be the area of most difficulty, in 2004, this grouped more towards simply application itself becoming a barrier and in 2005-2006, the border between understanding and application seems to have become the main barrier to progression for students who have not graduated. This suggests that although students from UNITE may be able to complete first level studies, which require more of knowledge, comprehension and some application, opportunities to develop higher order cognitive skills (extensive application and analysis) are not being realised. We acknowledge that this trend might not be peculiar to UNITE students alone, as the cognitive operations requiring HOTS are likely to be a challenge to all students. In the absence of a comparison with the mainstream, there is no data to validate the assumption therefore, it remains speculative and perhaps a subject for further research. Nonetheless, we find it very disheartening that the situation is worsening as the trend indicates that UNITE students are struggling with lower levels of the taxonomy which require simple application (see Figure 4 and 5).

Conclusions

The aim of this article was to explore the barriers to progression for UNITE students once they enter mainstream. While acknowledging the socio-historical factors of educational disadvantage as possible explanations for underperformance, the study on which this article was based extended the analysis of barriers to include the modules that students struggle with. These modules were analysed using Bloom’s taxonomy of the cognitive domain to ascertain the corresponding cognitive demands. The findings suggest:

- The progression and dropout rates of the UNITE cohort mirrors those reported in the literature
- The UNITE programme is successful in equipping students with the necessary skills to handle the curriculum at first year level
- UNITE students struggle with modules which require the cognitive operations of application, analysis, and synthesis.

This suggests an articulation gap between the cognitive demands that students develop in UNITE and the subsequent demands required in the mainstream. Engineering as an applied science, generally require students to operate at the levels of application, analysis and synthesis. Thus if the UNITE programme is to remain true to its mission of developing skills for academic excellence and successful graduation, there is need to articulate this gap. This will ensure adequate participation of UNITE students in the mainstream. In conclusion, it is hoped that this article will encourage dialogue between UNITE and mainstream academics to articulate this gap.

References


University of KwaZulu-Natal (2011). Faculty of Engineering: Handbook

Appendix A

Sample module outline description:

Mathematics 1A (MATH131)

Aim: To introduce basic mathematical concepts of differential and integral calculus


From the module description (short form given above), this module requires knowledge and understanding of mathematical concepts as well as the ability to apply them in a range of situations within the assessments. As such, it requires some analysis (level 3) along with demonstration of understanding of learnt techniques (level 2). This places the module between levels 2 and 3 on the scale used (straddling understanding and application. This would be listed as a 2.5+.
Developing Engineering Conceptual Competencies in Chemical Engineering Students through Socially Relevant DIY Projects

Suresh Ramsuroop

Department of Chemical Engineering, Durban University of Technology, South Africa.
ramsuros@dut.ac.za

Abstract

A consistent complaint by chemical engineering lecturers about their students is the lack of physical appreciation and interpretation relating to some foundational concepts such as dimensions of pipes, tanks, flow-rates, different types of pipe fittings, etc. In general, academic programmes in chemical engineering have limited learning activities to develop this key engineering competence. Whilst there are design modules in the curriculum, there is little or no learning activity that requires chemical engineering students to translate their design into a working prototype. To address this deficiency, a second year chemical engineering design module was reviewed and revised to include several hands-on learning activities to develop these basic engineering competencies.

Over the past three years, the chemical engineering design module in the national diploma has focused on developmental projects associated with sustainability, which emphasise hands-on learning. The primary objective was to adopt active learning methods that would: improve students’ physical interpretation and understanding of real engineering systems, expose students to the notion that chemical engineering can provide solutions to many of the challenges facing our society, develop the engineering hand skills (especially since very few students engage in any DIY activities), improve motivational levels in students, provide a platform for students to show creativity and innovation, and giving students a sense of ownership of their learning.

In the revised design module, students work in groups, with recent projects focusing on the design of modular potable water systems for rural applications. The key features of the module include: allowing students to take a design concept through to construction of an operational test rig, emphasising the hands-on and ‘realistic’ aspects of engineering; using the built test rig to collect key performance data, and analysis of the collected data to propose the size of a full scale plant. The commercial and societal relevance of the project is emphasised, as well as the importance for team-work. In addition, the project topics chosen also exposed students to: the social issue of provision of drinking water for rural communities; the use of alternative energy resources of solar and wind; and financial aspects related to project implementation, hence developing a range of skills and attributes required by engineering students. The learning activities in this module facilitate the development of several of the exit level outcomes as specified in the engineering qualification standards. The student surveys conducted in the module has repeatedly confirmed that several of the teaching, learning and assessment objectives are being realised through this teaching approach.

In this paper, a brief overview is presented on the development and implementation of this project at the Department of Chemical Engineering at the Durban University of Technology (DUT). It also discusses some of the challenges facing chemical engineering educators in: delivering a coherent academic programme that fulfils the required qualification standards,
creating a learning environment that motivates students to engage in learning, and improving the societal relevance of the academic programme.

Introduction

The list of competencies required in the new South African Engineering Qualifications Standards generated by the Engineering Standards Generating Body (ESGB), represents a cluster of skills consisting of cognitive, practical and social skills/attitudes coherently weaved together. These standards aim to ensure that new graduates develop a range of cognitive (knowledge and thinking), affective (attitudes) and psychomotor (skills) competencies. The redefining of qualifications has necessitated a rethink of teaching strategies and curriculum design on the part of educators in recent years. The driving objective of the education process is to find efficient ways to develop and assess a diverse set of qualification competencies. Hence, clear understanding of programme goals and objectives, teaching strategies to develop the required competencies, and assessment procedures which indicate whether established targets are being met, are integral components of a coherent educational process. Biggs (2003) who concluded that with any pedagogic approach, it is important to align learning outcomes, teaching and learning activities, and assessment tasks, particularly where the intention is to encourage deep, rather than surface, approaches to learning. Biggs calls this approach “Constructive Alignment” which entails the following steps: a) Defining the learning outcomes, b) Selecting learning and teaching activities that enable the students to develop the outcomes and c) Selecting appropriate assessment activities which allows the student to demonstrate that the outcomes has been achieved to the appropriate level.

Hence in order to meet the requirements as specified by the ESGB, the Department of Chemical Engineering at the Durban University of Technology (DUT) has reviewed the learning and assessment activities associated with its academic programmes. In particular, the design modules were reviewed, and based on discussions with colleagues and reflections on various pedagogical ideas, specific changes were made to the module which is intended to improve the student learning experience and fulfil several of exit level outcomes of the engineering qualification standards.

Teaching Design

An awareness of the theories of learning can provide some insight into understanding how university students learn. This in turn will impact on the design of the curricula and the teaching, learning and assessment (LTA) procedures to adopt. These considerations become important when the design of the syllabus to achieve the learning outcomes is being done. There is a general recognition that design should be at the heart of the engineering curriculum. It is recognised that design is one of the core activities that draws together a whole range of knowledge areas and skills and presents opportunities for students to practice higher skills such as dealing with uncertainty or incomplete data in a ‘real world’ or authentic learning environment. Design is a complex process of inquiry and decision making and often requires extensive collaboration between peers during the learning activity. There are many approaches to the teaching of engineering design, and these range from the traditional “paper design” where the focus is on calculation procedures of equipment / process /systems and associated engineering drawings, which may be based on individual / group study, to those which may also include prototyping, multi-disciplinary teamwork, societal, environmental and economic issues.

In recent years, the pedagogy associated with engineering design has been broadly defined by Prince and Felder (2006) as “inductive instructional methods” which encompasses active
learning, enquiry-led learning, problem-based learning (PBL), project-based learning (PjBL) etc. It has been defined as a teaching and learning strategy which develops higher order cognitive skills, disciplinary knowledge, and practical skills by placing students in the active role of practitioners confronted with a “real world” task. The Project Based Learning in Engineering (PBLE) Project (2003), completed by a consortium of UK universities, identified several key characteristics of this type of learning activity. These include: the use of context-based, real-life situations, requiring a range of cognitive skills (problem solving, analysis, decision making, critical thinking, and synthesis), requiring integration of interdisciplinary knowledge, promoting self-directed learning and developing lifelong learning skills, and involving the sharing and interacting with others in small groups. Another emerging engineering curriculum model is the CDIO Initiative (2004). The CDIO website introduces the initiative as follows: The CDIO Initiative is an innovative educational framework for producing the next generation of engineers. It provides students with an education stressing engineering fundamentals set in the context of Conceiving — Designing — Implementing — Operating real-world systems and products. With over 50 collaborating institutions from 25 countries worldwide, the group has produced a syllabus and a set of 12 standards which provide a comprehensive description of the level of knowledge, skills and attributes that engineering graduates should be expected to acquire using this framework.

It must be recognised that in using these types of teaching strategies, the intended learning can only be effective if it is engaged in actively by the learner. Hence, the lecturer’s task is to set up an environment of learning and assessment activities from which it is very difficult for the student to escape without the intended learning been achieved.

Module developments since 2009

The review of the design module in the national diploma presented an ideal opportunity to address a multiple of student deficiencies and to explore new pedagogies. A consistent complaint by colleagues and industrial mentors about our students is the lack of physical appreciation and interpretation relating to some foundational concepts such as dimensions of pipes, tanks, flow-rates, different types of pipe fittings, etc. In general, academic programmes in chemical engineering have limited learning activities to develop this key engineering competence. Whilst there are design modules in the curriculum, there is little or no learning activity that requires chemical engineering students to translate their design into a working prototype. To address this deficiency at DUT, a second year chemical engineering design module was reviewed and revised to include several hands-on learning activities to develop these basic engineering competencies. The key distinguishing features between the original design module and the revised module is presented below.

Traditionally this module’s delivery and assessment centred on a single “paper design” of a major separation process and its associated pipeline and heat transfer equipment, including: hazop studies, environmental impact studies and use of simulation packages. Whilst the teaching strategy was student centred, the solution process remained mainly theoretical and focused the application of equipment design methods. It was felt that the learning process could be enhanced if it included some “fun” activities that required students to build equipment and compete with each other, similar to what was being done in the other disciplines of engineering. Since 2009, this module has been revised and this module’s delivery and assessment centres on 3 mini-projects which include:

a) A group mini project on pipeline design requiring students to take actual site measurements including the physical constraints. The design includes the actual costing of the proposed pipeline and its associated fittings.
b) A group mini project requiring “Build – Test – Upscale”. The details are outlined later in this paper.

c) A “paper” design on mass / heat transfer equipment done by individual students. Hence retaining some of the elements of the original module.

Over the past three years, the chemical engineering design module in the national diploma has been focused on developmental projects associated with sustainability which emphasise hands-on learning. The primary objective was to adopt active learning methods that would: improve students’ physical interpretation and understanding of real engineering systems, expose students to the notion that chemical engineering can provide solutions to many of the challenges facing our society, develop the engineering hand skills (especially since very few students engage in any DIY activities), improve motivational levels in students, creating a platform for students to show creativity and innovation, and give students a sense of ownership of their learning.

It is widely accepted that students are motivated by ‘real world’ or authentic learning experiences; Clifford (2005) suggested that this is even more apparent where there is an added social benefit. Khan and O’Rourke (2005) also reported that the extrinsic motivation of solving a real world problems were greatly enhanced when the identified goals included the sociological as well as the technological aspects. Since one of the requirements of the engineering qualification standard includes sustainable development, effort has been made to make it an integral part of this design module. The concepts of sustainability are introduced through a series of lectures based on the IChemE Publication (2007) “A Roadmap for 21st Century Chemical Engineering”. The key theme of the publication is: “What does society need; what are the desirable outcomes and how can chemical engineers work in partnership with others to make it happen”. Penlington and Steiner (2010) reported that engineering for sustainable development has a motivational value, and may be may be used to broaden the student’s perspective. In addition, addressing of social concerns and environmental awareness will illustrate the wider consequences of engineering activity. They further suggest that to develop self-reflection in graduates, the following principles should be considered:

a) help the learner appreciate why consideration of sustainability is in their interest

b) use appropriate pedagogies for active engagement with issues

c) help learners gain plural perspectives

d) encourage learners to continue thinking about issues beyond their formal education.

There is a general consensus that to improve student motivation, there is a need for modules to be more exciting, interesting and relevant to students.

For the “Build – Test – Upscale“ projects, the students work in groups, with recent projects focusing on the design of modular potable water systems for rural applications. The key features of the module include: allowing students to take a design concept through to construction of an operational test rig, emphasising the hands-on and ‘realistic’ aspects of engineering; using the built test rig to collect key performance data, and analysis of the collected data to propose the size of a full scale plant. The commercial and societal relevance of the project is emphasised, as well as the importance for team-work. In addition, the project topics chosen also exposed students to: the social issue of provision of drinking water for rural communities; the use of alternative energy resources of solar and wind; and financial aspects related to project implementation, hence developing a range of skills and attributes required by engineering students. The CDIO Initiative confirmed that Design-build type
projects provide a solid foundation to build deeper conceptual understanding of disciplinary skills. It also reported that “The emphasis on building products and implementing processes in real-world contexts gives students opportunities to make connections between the technical content they are learning and their professional and career interests.” The typical activities associated with “Build – Test – Upscale” Project are shown in Table 1.

The assessment criteria used for the assessment of the built equipment is presented in Annexure 1. An extract of the detailed assessment criteria used for the final report is presented in Table 2. These assessment criteria are presented at the beginning of the project and are discussed in detail during the duration of the project.

**Table 1.** Typical Student and Staff activities associated with the “Build – Test – Upscale” Project

<table>
<thead>
<tr>
<th>Week</th>
<th>Student Activity</th>
<th>Staff Activity</th>
<th>Notable outputs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Attend briefing lecture, collect project documentation (scope and detailed assessment criteria).</td>
<td>Introduce the project, describe assessment process and resources available.</td>
<td></td>
</tr>
<tr>
<td>2 &amp; 3</td>
<td>Design process begins, brainstorming etc., Develop project plan. Collect component packs.</td>
<td>Review meetings with each group to explore their understanding of the project</td>
<td>Project plan with Gantt chart</td>
</tr>
<tr>
<td>4</td>
<td>Report on initial designs, reflect on ‘practical issues’ of the design. Develop PFD of potential process.</td>
<td>Provide feedback on project plan. Discussion on submitted PFD. Review meeting with whole class</td>
<td>PFD of proposed process</td>
</tr>
<tr>
<td>5 - 7</td>
<td>Building stage of test rig.</td>
<td>Available for consultation Review meeting with whole class</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Testing and reflection on performance of test rig</td>
<td>Discussion of Assessment Criteria for Test Rig Demonstration. Available for consultation Review meeting with whole class</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Demonstration of test rig</td>
<td>Assessment of test rig Review meeting with whole class</td>
<td>Functional Test rig</td>
</tr>
<tr>
<td>10-11</td>
<td>Undertake experimental work using the test rig</td>
<td>Available for consultation Review meeting with whole class</td>
<td></td>
</tr>
<tr>
<td>12-13</td>
<td>Prepare the final technical report</td>
<td>Review of detailed Assessment Criteria of final technical report</td>
<td></td>
</tr>
<tr>
<td>14</td>
<td>Submit final technical report</td>
<td></td>
<td>Final Technical Report</td>
</tr>
</tbody>
</table>

**Student Assessment of the “Build – Test – Upscale” Project**

A Student Assessment consisting of ten closed questions, and three open questions, is conducted specifically for the “Build – Test – Upscale” Project. In addition, a standard institutional module assessment is conducted at the completion of the design module. Using a scale of disagree, agree and strongly agree, the results from 66 respondents for the 2011 project is shown in Figure 1. The results show the percentage distribution of responses to the ten closed questions shown in table 3.

Whilst there were favourable responses by majority of the students for most questions, questions 6 and 7 received less favourable responses. These questions related to the resources available for the building test rig, and the availability of lecturer for consultation. Whilst most of components to build the test rig were made available to students, some components had to be purchased by students, and there may have been limited access to equipment such as electrical and hand tools. The less favourable responses for lecturer availability may be due to fixed consultation slots on the time-table.
Table 2. Extract from Detailed Assessment Criteria of the Final Technical Report

<table>
<thead>
<tr>
<th>Literature Review/Study [20] – (sub-minimum 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extensive and relevant presentation of the theoretical basis for the project. Shows good understanding and integration of literature into the complete document</td>
</tr>
</tbody>
</table>

1. Literature:
   - Review of existing information about methods used for the production of potable water from a range of raw water sources. Highlighting the processes that are suitable for rural area applications.
   - The specifications for potable water are presented together with a brief discussion of the significance of each criterion.
   - The application of membranes to potable water supply is also investigated
     - Depth of review is appropriate to the level of study.
     - Review includes advantages and disadvantages related to the different methods.
     - A Range of sources of relevant literature are used.
     - Relevance of the literature to the particular area of research.
     - Integration of the literature is appropriate.
     - All sources of information are referenced correctly, both in text and in reference list

2. Theory:
   - Relevant fundamental theory applicable to the study has been identified and discussed.
   - Level of theory presented is appropriate to the level.
   - Relevant equations and correlations used has been fully stated and discussed together with the nomenclature (definition of symbols with their units).
   - Numbering/labelling of equations.
   - Diagrams and illustrations are appropriately integrated, labelled and referenced.

From the open ended questions the students commented very positively on their learning experiences. Majority of the students indicated that the project provided them the opportunity to learn new skills and apply their engineering knowledge. Some of the comments included: “enjoyed the real engineering experience”; “enjoyed making something that works”, “it made think critically and work under pressure”; “to conduct research and be creative”, “learnt real engineering skills”. On the open question on how to improve the module, almost all the students indicated that more time was required for the project.

![Figure 1. Student Survey Results](image)
Table 3. Closed Questions used in the Student Survey

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>This project has made me aware of some of the challenges facing mankind.</td>
</tr>
<tr>
<td>2.</td>
<td>This project has shown me that chemical engineering can meet some of the challenges facing mankind.</td>
</tr>
<tr>
<td>3.</td>
<td>The building of this project has improved my technical understanding of some general engineering and chemical engineering concepts.</td>
</tr>
<tr>
<td>4.</td>
<td>I learnt new skills during this project.</td>
</tr>
<tr>
<td>5.</td>
<td>Teamwork has significantly contributed to the completion of this project.</td>
</tr>
<tr>
<td>6.</td>
<td>Adequate resources were available for the completion of the project.</td>
</tr>
<tr>
<td>7.</td>
<td>The lecturer was available for consultation.</td>
</tr>
<tr>
<td>8.</td>
<td>The project requirements were well documented.</td>
</tr>
<tr>
<td>9.</td>
<td>The project requirements were discussed.</td>
</tr>
<tr>
<td>10.</td>
<td>The assessment criteria were documented and handed out.</td>
</tr>
</tbody>
</table>

Conclusion

The learning activities in this module facilitate the development of several exit level outcomes as specified in the engineering qualification standards. The student surveys conducted in the module has repeatedly confirmed that several teaching, learning and assessment objectives are being realised through this teaching approach. Some of the main benefits of learning engineering through the “Build – Test – Upscale” projects are:

- Students are encouraged to use a wide range of cognitive skills and to apply their theoretical knowledge to practical situations.
- The improvement of students’ physical interpretation and understanding of real engineering systems.
- Students develop a better grasp of theory and principles applicable to the project.
- Learning engineering through projects is fun for students.
- Students understand that engineering is practiced in non-ideal, poorly defined situations, and that there is no single right answer.

Improves the technological knowledge and skills (especially how to build things) that many of them lack when they started the module.

Develop an awareness of the role chemical engineering can play in improving lives of people and providing solutions to some of the global challenges facing the world.

- Several challenges still exist in the implementation of such projects, including:
- The “Build – Test – Upscale” projects, are expensive to run as they require funds to purchase materials and to provide appropriate supervised workshop facilities.
- Innovative assessment techniques are required for example: the assigning grades to individual students that reflect their work as members of a team.
- Regular and intensive supervision and monitoring is required to facilitate the learning process so that students engage in the intended learning and develop the required skills.
- Students find these types of projects time consuming and impacting on their time spent on other modules in the programme.
So while traditional detailed design concepts are vital in engineering practice, students need concrete experience in which to root these concepts. This hands-on experience not only reveals the challenge and excitement of design to the students but also enhances their learning experience and stimulates commitment to the academic programme.

References


**Annexure 1**

**DURBAN UNIVERSITY OF TECHNOLOGY**  
**DEPARTMENT OF CHEMICAL ENGINEERING**  
**Chemical Process Design III**  
**Solar Desalination Test Rig: Assessment Criteria**

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Assessment Criteria</th>
<th>Mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Identify the objectives of building the test rig</td>
<td>• The purpose of building the test rig is presented.</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>• The significance of the proposed experimental work is presented</td>
<td></td>
</tr>
<tr>
<td>Design and Construct “desktop” test rig</td>
<td>a) Key components / unit operations are clearly identifiable. For example: Heat exchangers; Solar concentrator; flash vessel; Venturi; product tank; Activated carbon column; etc</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>b) All vessels, pump, electrical wiring, piping and fittings neatly and correctly assembled</td>
<td></td>
</tr>
<tr>
<td></td>
<td>c) Assembly facilitates easy measurements of key variables: Flow-rates of various streams; Operational pressure, Temperatures, etc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>d) Unit allows for easy replacement of key components.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>e) Test rig assembly is ergonomic i.e all components are easily accessible</td>
<td></td>
</tr>
<tr>
<td></td>
<td>f) Optimal use of the number of valves and fittings.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>g) The test rig is easily portable.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>h) The rig has a minimum footprint.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>i) The unit is structurally strong</td>
<td></td>
</tr>
<tr>
<td></td>
<td>j) Measuring and control device/s instruments correctly installed and appropriate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>k) The assembled test rig shows engineering competence</td>
<td></td>
</tr>
<tr>
<td>Commissioning and demonstration of the rig.</td>
<td>a) Test rig has no leaks.</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>b) The operation of the unit is demonstrated in a clear, articulate and professional manner. The following is expected to be demonstrated:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Fully operational rig</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Measurement of the various key variables</td>
<td></td>
</tr>
<tr>
<td>Knowledge</td>
<td>Knows and understands scientific terms, facts, concepts, principles, theories relevant to the test rig:</td>
<td>20</td>
</tr>
<tr>
<td></td>
<td>• Identification of key operational variables</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Operating principles of the key pieces of equipment: eg. : Heat exchangers; Solar concentrator; flash vessel; Venturi; Activated carbon column; etc</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Suggestions on improvements to enhance performance.</td>
<td></td>
</tr>
<tr>
<td>Creativity</td>
<td>• Evidence of some original expression in the design of the test rig</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>• Evidence of creative approach to addressing design limitations</td>
<td></td>
</tr>
</tbody>
</table>
Implementation Experience with Project-Based Inductive Learning in an Introductory Undergraduate Module in Nuclear Engineering

D.E. Serfontein\textsuperscript{1} and J.I.J. Fick\textsuperscript{2}

\textsuperscript{1}School of Mechanical and Nuclear Engineering, North-West University, South Africa; \textsuperscript{2}Faculty of Engineering, North-West University, South Africa.

\textsuperscript{1}Dawid.Serfontein@nwu.ac.za, \textsuperscript{2}Johan.Fick@nwu.ac.za

Abstract

Over the past few years three undergraduate modules in Nuclear Engineering have been introduced into the four year Mechanical Engineering degree program; two at third year level and one at final year level. Initially the conventional didactic approach of first teaching basic nuclear physics and to then introduce design, synthesis and application in later modules was followed. This approach led to low motivation and aversion to the large volume of nuclear physics being taught as a basis for later development. As a response, the teaching/learning strategy was inverted, commencing with a global approach and progressing to the theoretical and mathematical treatment of the subject in the fourth year. Group project-based inductive learning with peer assessment was introduced as a teaching/learning strategy. The implementation process of the new strategy was operated as an evidence-based research project and monitored by means of questionnaires, statistical analysis of grades, qualitative analysis and observation by lecturers. The results for the four students of 2009 are reported in this paper. Due to this very small sample size, the results were not statistically significant. However, early indications suggest that this method is effective in helping the students to see the “big picture”, stimulating their interest, introducing them to and increasing their ability to do research, enhancing their professional engineering competencies in terms of better report writing and audiovisual presentation and debating skills and, most importantly, setting the context within which the theoretical and mathematical treatment of the subject would be developed in later modules. Peer assessment, critical for evaluating group work, did, however, present significant challenges which reduced the sensitivity of the assessment and thus reduced the incentive for students to work hard.

It was thus concluded that the strategy of group project-based inductive learning has strong benefits, but that quality assurance in respect of peer assessment had to be improved.

Introduction

North West University has been offering a Masters Degree in Nuclear Engineering since 2005 with a high degree of success. However, the students feeding into the post graduate programme from the four year undergraduate mechanical engineering degree program did not have the benefit of any undergraduate training in nuclear engineering or nuclear physics. In response an undergraduate specialisation in nuclear engineering in the school of Mechanical Engineering was conceived. As a precursor to a fully specialised program, it was decided to offer three introductory elective modules, two in the third year and one in the fourth year of the mechanical engineering program.

Initial experience with introducing fourth year Mechanical Engineering students to nuclear engineering showed that students without a thorough background in nuclear physics often struggled to grasp the foreign concepts of neutron physics, and to construct a rationale and
context for the required learning. It was found that if the traditional deductive approach of first confronting the students with the basic theoretical nuclear science, before integrating this into the bigger and less foreign picture of engineering applications were followed, many of the students became disheartened with and demotivated for the module.

Therefore, in designing the three modules, it was consciously decided to deviate from the traditional approach in that:

1. The “big picture” of the opportunities and challenges facing the global nuclear power industry were introduced first.
2. Inductive learning methods were used.
3. Nuclear reactor concepts were first introduced by means of user friendly computer simulations. The nuclear physics theory required to understand and analyse these newly discovered phenomena, were then introduced in a just-in-time manner.
4. Project-based learning was used in order to continuously integrate the theoretical concepts learned with the solution of real world problems.
5. Only open-ended assignments were used for assessment, i.e. there was no rigid set of right or wrong answers: students could earn good marks for any position they would adopt, providing that they could motivate it on the basis of rigorous scientific research.
6. Some of the so-called “soft skills” among the professional engineering competencies specified in Exit Level Outcomes of the Whole Qualification Standard for the Bachelor of Science in Engineering (BSc(Eng))/ Bachelors of Engineering (BEng) degrees (ECSA, 2004) are not easily developed/assessed in traditional deductive modules. Therefore the following were specifically targeted:
   a. Exit level outcome 6: **Professional and technical communication skills** were stimulated in that projects were assessed by means of project seminars in which each student had to give a verbal presentation supported by audiovisual aids and had to defend his/her presentation before a panel of experts.
   b. Exit level outcome 7: Insight into the **impact of engineering activity** was enhanced by prescribing projects on the environmental impact of the different energy technologies, including studies on nuclear waste and global climate change.
   c. Exit level outcome 8: **Team work** skills were developed in that all projects were assigned as group work.
   d. Exit level outcome 9: A culture of life-long learning and **independent learning ability** was stimulated in that these groups had to design their own project strategies and had to independently perform the related searches for peer reviewed scientific articles.
7. Grades for projects were distributed among the members of the group based upon the contribution of each member, as determined by means of a **peer assessment** methodology.
8. The implementation process was run as an evidence-based research project and thus the efficacy of these strategies were monitored by means of questionnaires and other quantitative and qualitative observations, for which the results are reported below.
Theoretical framework

The researchers based their design of these modules on the following understanding of the task of the engineer.

The task of the engineer differs significantly from that of the research scientist, in that the ability to design lies at the heart of the task of the engineer. In this process he/she makes use of the laws and principles of nature discovered by research scientists, such as physicists, chemists and mathematicians. Due to the nature of their fields, these scientists occupy themselves mainly with trying to discover new laws and principles of nature. Therefore they normally specialise intensely, i.e. they focus intensely on these new problems and thus place less emphasis on the much larger body of known and more familiar knowledge. These research aims readily lend themselves to a focus on analysis and deductive reasoning. However, when a team of engineers try to, for instance, design a more efficient machine, they cannot afford to ignore certain relevant parts of the available body of knowledge simply because it is known and familiar. They must also take into account all relevant fields of knowledge, such as fuel chemistry, materials, aerodynamics, thermodynamics, legal requirements, pollution limits etc. Therefore engineering teams tend to specialise in a much smaller measure than scientists. They also need to do much more synthesis, compared to analysis. This required ability to see and optimise the “big picture” is much more readily developed by inductive than deductive teaching/learning.

Theory of learning: The continued scientific revolution has created a massive amount of knowledge which is still proliferating at an exponential rate. This has made impossible the traditional aim of getting students to memorise a substantial fraction of the facts relevant to their field. Moreover, the information revolution, and especially the internet, has placed this abundance of information at the fingertips of a large part of the global population, thereby dramatically reducing the value of being a “walking encyclopaedia”. Rather, the goal of education should now be to guide students to develop the intellectual tools and learning strategies needed to efficiently acquire and process the relevant knowledge of their respective fields. (Bransford et al, 2000: 5.) Gaining deep understanding of this knowledge has become much more important than mere memorisation of the facts. However, possessing a deep foundation of usable memorised knowledge remains important to efficient problem solving (Bransford et al, 2000: 9). Understanding this memorised knowledge in the context of a conceptual framework, being able to organise it in ways that facilitate retrieval and application and knowing the types of problems to which each chunk of knowledge is applicable, are essential, especially in order to be able to transfer existing knowledge to new problems and to use it to create innovative solutions. (Bransford et al, 2000: 16-17; 31-44; 51-58; 62-63).

Inductive and project/problem/case-based learning: Learning with understanding is strongly enhanced if students first engage a problem before learning the theory applicable to its solution (Bransford et al, 2000: 59; 77). However, it is essential to guide students to see how the abstract elements of the solution to one problem can be transferred to other problems (Bransford et al, 2000: 62-66). Brophy & Velankar (2006) and Kitto (2009) gave literature overviews on such “anchored inquiry” or inductive learning in undergraduate engineering courses. Kitto (2009) reported large improvements in student output, including higher order thinking and language skills, after replacing deductive with inductive teaching. This included many elements of a student-centred approach such as cooperative learning, case-based learning, active/inquiry learning, concept learning, problem-based learning, and constructive alignment.
Group-based projects and peer assessment: Group-based projects are highly rewarding, and are accepted as an important part of engineering education by students, prospective employers and accreditation boards (Hemer, 2008). Especially from the perspective of employers, it is not only the quality and quantity of an individual’s contribution to the group’s project that is important, but especially the individual’s ability to function as an effective team member and to add value to the team dynamics. It is obvious that the lecturer cannot assess these aspects directly, since he is not involved behind the scenes where the group members are interacting. Therefore peer assessment is a strategy to address this shortcoming, so that each team member can serve as a proxy assessor for the lecturer.

However, assessing the contribution of individual students to group-based projects in a fair and balanced manner remains a challenge (Hemer, 2008). From the detailed literature review presented by Hemer, it is clear that peer assessment is confronted with a substantial number of problems including ulterior motives among group members. When self-assessment is included, self-enhancement, i.e. unreasonably optimistic self-appraisal, can be problematic (Van Duzer & McMartin, 2000). Therefore the efficacy of peer assessment is closely related to the suitability of the specific assessment technique to the specific project’s needs and to the standard of quality control by the lecturer (Hemer, 2008). More detailed and more specific assessment guidelines generally work best.

Carlson et al (2005) successfully used Calibrated Peer Review, a free web-delivered, collaborative learning environment, to facilitate peer review, which included self review. Team Developer is another automatic peer assessment tool, which includes the detailed assessment of the outcomes required by the ABET EC 2000 accreditation standard (McGourty et al, 1998). Van Duzer & McMartin (2000) developed a peer assessment system that focuses on the measurement of each member’s contribution to the group dynamics. Their results reported a challenge that was also reported by the other studies, i.e. that students tend to give the same score to all group members, which reduces the sensitivity of the measuring instrument. They responded with various interventions, which strongly enhanced the sensitivity of their technique.

It is thus clear that the potential value of group work and peer assessment is unquestionable. However, this potential will only be realised to the extent to which the measuring instrument is fine-tuned to the specific needs of a project and to which rigorous quality control is applied.

Project Implementation

The implementation experience with these two introductory third year modules will be reported. However, all experimental results refer to the four students in the 2009 Nuclear Energy (NUCI 321) group only. Due to this very small sample size, the results were not statistically significant and can only serve as early indications of what might be found by larger follow-up studies.

Structure of modules

Nuclear Energy (NUCI 321) was designed to introduce students to the big picture of the challenges and opportunities facing the global nuclear energy industry. The second module, Nuclear Engineering I (NUCI 326), was more technical in nature and used a PC-based industry standard nuclear power plant simulator code and a guided self directed learning approach to introduce students to the operation and control characteristics of a pressurised water nuclear reactor. The students were also introduced to the mathematical physics theory behind the operational phenomena that they had just discovered on the simulator. This theory
was taught mainly on a conceptual level, while the more detailed mathematical deduction of these formulae was deferred to the follow-up module in the fourth year.

For Nuclear Energy, the module objectives were stated as:

“To provide the student with a set of learning activities which will allow him/her to develop knowledge and understanding of the opportunities and challenges facing the global nuclear energy industry and to gain basic technical knowledge of major types of nuclear reactors and nuclear fuel cycles, in order to be able to select the most applicable technical options, in the light of the stated global nuclear energy policy issues.”

Six broad project themes were covered in bi-weekly cycles, starting with an introductory talk on each new theme, followed by intensive guided self-study, in the form of group work and an automated elementary individual preparation test on the university’s educational website, eFundi. The assessment of the team’s performance regarding each theme culminated in a project seminar during which the group had to make the case for the view which they had adopted on the theme-question. They also had to submit a written group report on this theme. After each seminar, each student had to submit a short written reflection in which they had to give a synthesis of their insights gained.

During each project seminar a panel of lecturers, including an expert from industry, assessed the level of attainment of the outcomes for the group as a whole, as well as for each of the four individual members in the group. These assessments focused on the effectiveness of their presentations, debating skills and levels of knowledge and insight demonstrated.

The composite of each student’s individual grades, averaged over all six themes, contributed toward 40 % the semester grade, while the remaining 60 % was made up by the distributed group grades. This semester grade then contributed towards 60 % of the final module grade, while the final individual examination made up the remaining 40 %.

Each theme’s group grade was distributed towards the students in direct proportion to the score which each student obtained from the assessment by his/her peers. The peer assessment was based on an unpublished method, developed by Mr. André Hattingh from the Faculty of Engineering at the North-West University: on the peer assessment form, each student had to score his own, as well as every other group member’s contribution towards attaining the group grade. The four areas of contribution which were assessed were brain-storming and ideas, research, writing of the group report and compilation of the Power-Point presentation. For each of these areas, the average of the group’s contributions was normalised to 100%. These were then averaged over all four areas.

This implied that if the group-grade, assigned by the panel of lecturers, was for instance 70%, a student who was assessed by his peers to have made an average (i.e. 100%) contribution to the group’s deliverables, would receive this same 70% as his/her individual grade. A 110% contributor would thus receive an individual grade of 77%, while a 70% contributor would receive 49% and would thus fail the group aspect of that seminar etc.

Final Examination

The final examination was based on an individual mini project, in which each student had to calculate and compare the lifecycle cost of a typical nuclear power plant to that of a coal-fired power plant.

Before the final examination each student had to submit a written personal portfolio document (PPD) in which he/she had to provide comprehensive documentary evidence to support his/her claims to having achieved each of the stated module outcomes. In these PPDs the students were to reflect again on each theme with the benefit of the wisdom of hindsight
and to state a well motivated personal final conclusion regarding the central question of each theme. Students were also instructed to structure all the materials in their PPDs in such a way that each piece of evidence explicitly aimed to prove to the assessors that the student had attained a specific outcome.

The final assessment took the form of an oral presentation in which each student had to present and defend his/her PPD, with special focus on the mini project, before a panel of examiners.

**Experimental methods**

Since there was no control group, objective empirical comparative measurements were not possible and therefore the results of this study will be presented largely as:

1. the results of a questionnaire in which the students rated their subjective experience of the pedagogical approach in this module, compared to other subjects,
2. a statistical analysis of the peer assessment scores assigned by the students, compared to grades assigned by the panel of assessors and
3. the lecturers’ subjective experience of the efficiency of this approach, based on close observation of and discussions with the students and with other lecturers.

**Students’ perspective**

All four 2009 students completed a questionnaire in order to assess their perception of the extent to which they benefited from the project based inductive learning approach, compared to the more traditional analytical/deductive approaches in their other modules. For each question this benefit had to be scored according to the scale indicated above Table 3.

**Results**

The average final module grade for 2009 was 71.0 %, with a minimum of 63% and a maximum of 76%.

None of the 2009 students complied significantly with the instruction to structure their PPDs in such a way that each piece of evidence explicitly provided proof to the examiners that a specific outcome had been attained. It was therefore clear that the students were not able to bridge the gap between the traditional technical discussion of the subject matter and this more scholarly approach in which they had to restate each technical piece of information in terms of its pedagogical function. From the students’ oral defences of their PPDs, it was, however, clear to the assessors that the students did indeed attain these outcomes. Therefore this specific requirement for the format of the PPD was omitted in 2010.

**Lecturers’ perspective**

The lecturers and assessors were impressed by the levels of initiative and self motivated learning which this approach instilled in the students. The invited external evaluators also stated that it was abundantly clear that the objective of stimulating the students to see the “bigger picture” was attained at a very high level.

However, the peer evaluation presented significant challenges. Projects 1 to 3 were considered outliers because the team was still busy fine-tuning the peer assessment method. Especially problematic was inflated self-assessment. Psychologically this was to be expected since it is a well known aspect of human nature that people normally view their own achievements in a more favourable light than they would view similar achievements coming from a peer. This was addressed by specifically warning the students to guard against this.
practice. One of the students was also absent during the project seminar of theme 3. Therefore, only the results for Themes 4 to 6 were included in the analysis.

Table 1 shows, for each project, the ratio between the score that each student assigned to his/her own contribution towards the group deliverables and the average score that his/her three peers awarded for his/her performance. From the table it is clear that, on average, each student assessed his/her contribution to the group deliverables 6 ± 3% higher than did his/her peers. Due to the small sample size, these results are not viewed as statistically significant, but rather as early indicators of what might be found by larger follow-up studies. This also concurs with what was reported from the literature in the theoretical framework above.

**Table 1. Ratio of self assessment to assessment by peers.**

<table>
<thead>
<tr>
<th>Project</th>
<th>Self assessment / (Average assessment by peers)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 4</td>
<td>1.090</td>
</tr>
<tr>
<td>Project 5</td>
<td>1.032</td>
</tr>
<tr>
<td>Project 6</td>
<td>1.055</td>
</tr>
<tr>
<td>Average over themes</td>
<td>1.059</td>
</tr>
<tr>
<td>Standard Deviation</td>
<td>0.029</td>
</tr>
</tbody>
</table>

Table 2 highlights the differences between the spreads in the grades for the four students as determined from the averages of the peer assessment scores by all four students, compared to the grades assigned by the team of expert assessors. These assessments are, of course, not directly comparable. While the students scored measuring only the relative contribution of each peer, the team of expert assessors graded the absolute value of the performance of each student. Also, the students scored the contribution of each participant during the preparation for the seminar, while the assessors graded the performances during the seminar. These, however, should be expected to be correlated: a student who contributed strongly to the brainstorming and research in the preparations phase can be expected to therefore also perform well in arguing the case, demonstrating knowledge etc during the seminar, i.e. input during the preparation phase can be expected to be strongly correlated with output during the seminar. Therefore it is reasonable to expect that the variations in these input assessment scores by the students should be similar to the variation in the output assessment grades by the assessors. However, Table 2 shows that this was not entirely the case:

The standard deviation of 5.9 % assigned by the assessors is almost double the 3.6 % which the students assigned to their peers. Due to the very small sample size, this result is not statistically significant. However, if this is an early indication of what might be found by larger follow-up studies, the implications would be significant:

Since the total range of a normal distribution is reasonably approximated by the average ± 2 Standard Deviations, the typical range for a similar group of students would be from about 59% to 83% if only the assessors would do the grading, while it would range only from 64% to 78% if only the students would perform the assessment. Such a reduction in spread may have serious repercussions in that it will strongly reduce the probability of students either failing or passing the module with distinction, thereby reducing the incentive for hard work.
Table 2. Comparison of the spread of grades awarded by the assessors to the spread of peer assessed scores

<table>
<thead>
<tr>
<th>Project</th>
<th>Average ± Standard Deviation of grades assigned by assessors (%)</th>
<th>Standard deviation of relative contributions, scored by peers (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 4</td>
<td>72.8 ± 9.3</td>
<td>± 5.1</td>
</tr>
<tr>
<td>Project 5</td>
<td>72.0 ± 2.2</td>
<td>± 3.1</td>
</tr>
<tr>
<td>Project 6</td>
<td>69.0 ± 6.2</td>
<td>± 2.6</td>
</tr>
<tr>
<td>Average over projects</td>
<td>71.3 ± 5.9</td>
<td>± 3.6</td>
</tr>
</tbody>
</table>

This difference was possibly due to the psychological factor of peer pressure, which may have caused the students to be, compared to the lecturers, less willing to penalise their friends with low marks when their contributions were below standard. Since the group grades assigned by the assessors were distributed towards the students proportional to the individual scores assigned by the students, the lecturers had a monopoly in assigning the group grades, while the students had a monopoly in distributing these grades amongst themselves. This means that if a group of students were to collude, either in discriminating against or for a specific individual, or in awarding almost identical scores to all members of their team, this would seriously impair the integrity of assessment. Therefore this method of assessment can only be applied with confidence if good quality control is exercised by the lecturer.

The students’ tendency to award themselves unrealistically high scores (Table 1) may potentially present a further threat to the integrity of the peer assessment system and may, on the surface, seem to suggest that each student should only be allowed to judge the contribution of his peers and not his own contribution. However, this challenge is less severe than it may seem, since, if every student were to award himself an unrealistically high relative score, these anomalies will cancel each other out when the group averages are normalised to 100 %. What is more, this problem may actually hold the key to incentivising students to award more realistic spreads of scores to their peers, as will be shown below.

Students’ perspective

The key for the interpretation of the extent of benefit assigned for each question in Table 3 was:

-1 = Less than
0 = The same
1 = A bit more
2 = > 50% more
3 = At least twice
4 = At least 4 times
## Table 3. Student perception assessment questions and scores.

<table>
<thead>
<tr>
<th>Nr.</th>
<th>Question</th>
<th>-1</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>To what degree did you enjoy this subject, compared to other subjects?</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>How difficult did you find catching on to the inductive learning approach, compared to the traditional approach?</td>
<td></td>
<td></td>
<td>3</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>To what extent has the inductive learning approach helped you to better understand the &quot;bigger picture&quot;, that is the policies and politics behind this industry, compared to other subjects?</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>To what extent has your knowledge regarding the basic principles of this engineering discipline grown during this module, compared to other subjects?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>To what extent has your ability to do research increased, compared to other subjects?</td>
<td></td>
<td></td>
<td>1</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>How much has this approach increased your ability to write a good scientific report, compared to other subjects?</td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>How much did you need your lecturer's assistance during the semester, compared to other subjects?</td>
<td></td>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>How hard did you need to work in NUCI 322, compared to other subjects?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>9</td>
<td>To what extent did NUCI 322 capture your interest and stimulate your initiative, compared to other subjects?</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>To what extent did you find the web-based preparation tests helpful, compared to modules without such tests?</td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>To what extent did the peer assessment system improve the co-operation and productivity within your group, compared to group work in modules without peer assessment?</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>12</td>
<td>To what extent did your peers rate your contribution to the group effort fairly, compared to modules where only the lecturer assigned grades for group work?</td>
<td></td>
<td></td>
<td>2</td>
<td>1</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>13</td>
<td>To what extent did this module improve your debating and public presentation skills, compared to other modules?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>14</td>
<td>To what extent did the mini project on the comparison of the life cycle costs of coal-fired vs. nuclear power plants help you hone your professional engineering skills, compared to other modules with traditional closed book examination papers?</td>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>15</td>
<td>To what extent did the final assessment by means of the defence of your personal portfolio in front of a panel of assessors help you to hone your professional engineering skills, compared to other modules with traditional closed book examination papers?</td>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>16</td>
<td>To what extent did the inductive learning approach help you to improve your grades for NUCI 322, compared to modules with a more traditional approach?</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>3</td>
<td>1</td>
</tr>
</tbody>
</table>
In conclusion, how would you rate the total value which the inductive learning approach added to your development as an engineer, compared to other subjects?

17 How would you appreciate it if the faculty were to change all your modules to the inductive learning approach?

18 In interpreting Table 3, it should be borne in mind that four students is a very small group, which impaired the statistical reliability of the test. This compares to typical class enrolments of 30 to 80 students in other subjects in this programme. Therefore, apart from statistics, the small group caused the relationship between the lecturer and students to become quite warm and personal and allowed the lecturer to give much more individual attention to students, compared to other subjects. This can be expected to have improved student performance and encouraged positive bias in the students towards the project, thereby skewing the results.

Furthermore the scoring scale was not balanced: since “0” meant “the same as other subjects”, the scoring range of “-1” to “+4” allowed only one option for indicating “less than” other subjects, compared to four options for indicating “more than” other subjects. This unbalanced scoring range was chosen because, from individual discussions with the students and other lecturers, it was clear that this module differed greatly from other subjects in the programme. While the students perceived some of these differences as much better and others as much worse, compared to other subjects, it was clear from the outset that perceiving this module as similar to other subjects was not a likely outcome of the study. Therefore the purpose of the questions were not primarily to establish whether students perceived this module differently, but rather to measure the extent to which they perceived it differently. Nonetheless this unbalanced scale can be expected to have skewed the results towards “more than”. Therefore replacing it with a balanced scale in follow up studies is recommended.

The questions for which the scores stood out were marked in bold in the table. From these, early indications are that the inductive approach was perceived as effective in:

- helping the students to see the “big picture”,
- stimulating their interest,
- introducing them to and increasing their ability to do research,
- enhancing their professional engineering competencies in terms of better report writing and audiovisual presentation and debating skills.

However, their perceptions of peer assessment seem to be a mixed bag:

- The scores for Question 11 indicates that three students perceived peer assessment to have improved the group dynamics by between 50% and 4 times. However, one student disagreed.

- Moreover the lower scores for Question 12 indicate that the students were not strongly convinced that peer assessment enhanced the fairness of the assessment.

Lastly (question 18), and not totally surprisingly, the students were in agreement that they would not appreciate faculty wide implementation of the current version of inductive learning:
In discussions with lecturers from other institutions, it became clear that this student response, i.e. “Inductive project-based group work is fantastic, but please just do not give us more of it”, is almost universally reported.

In all fairness, it should be conceded that the lecturers are in agreement with the students that the workload for this module was far too high. Since the engineering students already suffer from a heavy workload, it can realistically be expected that if the current version of this approach was implemented across all modules, the students would simply be snowed under by the workload and that the failure rate would thus increase dramatically. Therefore improving the method before wider implementation, is considered essential.

Lastly, this negative response may be interpreted as a positive sign that the loopholes in the traditional deductive analytical examination system, i.e. that it is possible to cram-swot a lot of formulae and facts just before the examination and to reproduce these from memory, without real insight into its meaning, has effectively been plugged by the present method. Since this is well known to be a standard survival strategy for many students, plugging this loophole may understandably not been appreciated by some.

Students also had the option to give general comments. Almost all students answered that they found the inductive approach very stimulating, but that the module required too much work, compared to similar credit modules. This correlated with their answers to Question 9 and with the observations of the lecturer.

Follow-up interventions

Due to the legitimate complaint of the 2009 students about the heavy work load, the number of projects in the module was reduced from six to four in 2010, which significantly reduced the problem.

Modifications to the peer assessment system

From the lecturer’s perspective, the main challenges experienced with the peer assessment in 2009 was that:

1. Students consistently assessed their own contributions higher that those of their peers.

2. Students seemed not to be very interested in the assessment of the contribution of their peers. After having assigned themselves the top score, students would either assign virtually identical scores to all the other group members, or would perhaps assign a slightly lower score to only one member and then identical scores to the other two.

3. The spreads in peer scores were consistently small, thereby reducing the sensitivity of the assessment. It seemed that peer pressure and the bonds of friendship within this small group prevented significant penalisation of those members that underperformed.

In order to attempt to mitigate the over assessment of own contributions, the system was modified in 2010 so that no self assessment was allowed. However, instead of encouraging more objective assessment of their peers, this led to disinterest in the peer assessment system as such. It thus became a struggle to get students to submit their assessments in time or to pay proper attention to it.
From this it was concluded that it would be more realistic to try and actively make use of students’ sense of self-interest/self-preservation, rather than to try and oppose it. Therefore the following modifications are proposed for follow-up studies:

1. Self assessment, including an overestimation of own contribution, should be allowed, as in 2009.

2. However, the price that each student needs to pay for this privilege is proper assessment of his/her peers. Therefore the lecturer will disqualify a student’s assessment form if:
   a. an unrealistically small spread in scores is assigned to peers,
   b. there is an obvious and gross mismatch between the scores assigned by the student and the grades assigned by the expert assessment panel, or
   c. ulterior motives are revealed, such as giving lower scores based on personal enmity etc.

3. The study should be repeated with larger groups, using a balanced scoring scale, in order to improve the statistical reliability of results.

4. The work-load should be reduced, in order to facilitate implementation of the method by more lecturers in more modules.

Conclusions
The theoretical framework presented indicated that group project-based inductive teaching/learning is a rich formative method that is especially beneficial to engineering education. This was confirmed by the results which gave early indications that it was effective in:

- helping the students to see the “big picture”,
- stimulating their interest,
- introducing them to and increasing their ability to do research,
- enhancing their professional engineering competencies in terms of better report writing and audiovisual presentation and debating skills.

However, the method is:

- labour intensive from an academic staffing point of view,
- time intensive from a student perspective – but strongly self motivational.

Peer assessment proved valuable, but presented significant challenges. Therefore several proposals were given in order to improve quality control in follow-up studies.

References


Using a 4D Virtual Reality Learning Environment to Follow the Evolution of an Engineering Project

David C Shallcross¹, Jo Dalvean¹, Roger Hadgraft¹, Ken Mann², Mariano Sola³, Ian Cameron⁴, Caroline Crosthwaite⁴, Nicoleta Maynard⁵, Moses Tade⁵ and John Kavanagh⁶

¹Melbourne School of Engineering, University of Melbourne, Australia; ²City West Water, Melbourne, Australia; ³Tedra, Melbourne, Australia; ⁴School of Chemical Engineering, University of Queensland, Australia; ⁵Department of Chemical Engineering, Curtin University, Australia; ⁶Department of Chemical and Biomolecular Engineering, University of Melbourne, Australia

¹dcshal@unimelb.edu.au

Abstract

A new interactive learning environment that allows engineering students to follow the construction of a water treatment facility is described. The learning environment is built around the use of a series of spherical images compiled from high resolution photographs. Using intuitive controls the user can move from one spherical image node to another taken either at the same time but in a different location within the facility, or taken at the same location but at a different time. Between May 2010 and April 2011 sixteen complete photographic surveys of the water treatment facility owned by City West Water in Melbourne, Australia were collected. Each survey consisted of 26 viewed nodes with the exception of the final survey which contains 77 nodes. The water processing facility treats the effluent from a more conventional sewage treatment facility, producing recycled water of two grades – one for use as irrigation water and one as an industrial grade. The facility makes use of ultrafiltration and reverse osmosis processes to remove the contaminants including high salt levels from the effluent water. The interactive virtual reality learning environment constructed for the facility allows students to follow the construction through from the initial construction phase to final operation. The system allows students to work at their own pace, following facets that interest them. While photography is now complete the learning environment is currently under development and will be ready for use in the classroom in 2012. This paper describes the learning environment as well as the intended learning outcomes.

Introduction

The teaching of design is a vital thread that should run through any engineering curriculum starting at first year and culminating in a major project in the students’ final year. Yet design is also a topic that is often taught by a series of unrelated and un-integrated open-ended problems that fail to make the appropriate links to the bigger picture beyond the individual subject, and certainly beyond the discipline. It is often not until their final year that engineering students get the opportunity to integrate their learning across all their subjects into a capstone design activity. Several studies have been conducted that emphasize the importance of introducing students to design concepts early in their courses (Cardella et al., 2008; Edward, 2004; Nesbit et al., 2005)

Because of the timescale of many major projects, engineering students rarely get the opportunity to experience and understand the complete life cycle of a major engineering
project be it a structure, machine, network or a process. The life cycle of a project consists of a number of important stages that may include some or all of the following:

- problem identification – what is the problem and what is the need that needs to be addressed, leading to a particular engineering solution which may involve the development of a new process, product, structure, network or processing facility,

- scoping design and feasibility study – in the commercial world there are a series of gates or hurdles that projects must pass through before being allowed to proceed to the next stage. The scoping design and feasibility study takes an idea and examines how difficult it might be to implement in practice. Factors considered include financial, legal, environmental, political and commercial considerations,

- conceptual design and business case – in this stage initial designs are developed and a business case is prepared allowing an informed commercial decision to be made on the project,

- detailed design – here the best conceptual design is taken into the detailed engineering design phase where all necessary equipment, safety, controls and layout issues are decided and where procurement for constructed is initiated,

- execution or implementation – the project is executed and the approved design is implemented. This might involve the construction of some processing facility. It will always be a multi-disciplinary activity involving engineers and other people with a range of backgrounds. The project may well involve several iterations of the design before this stage is complete,

- operation – the new process, product, structure, network or processing facility is operated,

- close-out or retirement – at the end of a project life cycle the operation is completed and the main components of the project are decommissioned and recovered or recycled.

Engaging students effectively across all the life cycle stages is extremely difficult in educational environments. Engineering educators need novel ways of engaging students with the life cycle stages, contextualizing design and operations, and understanding the important interactions that exist at all levels within the larger design picture. Students need to understand the important decision making processes that accompany life cycle issues and key socio-environmental settings.

This paper describes a novel learning environment currently being developed which will capture the design thinking and reasoning around engineering designs across all stages of a project from the identification of a need through to the retirement of a project. The learning environment will seek to present to the student the interactions between and perspectives of not just the engineers but the key project stakeholders that include the community, regulators and financial controllers.

Over the past six years the authors have developed a series of immersive and interactive virtual reality learning environments that allow students to explore chemical processing facilities in their own time. The foundation of the interface is a series of 19 high-resolution, spherical photographic images captured throughout the unit on three different vertical levels. The software used to generate the images allows the user to pivot their viewpoint both horizontally and vertically, as well as zooming in and out. Users may step between adjacent
nodes using hot spots embedded in the image or by selecting nodes from a map of the facility. The first such learning environment was built around the Crude Distillation Unit #2 of BP’s Bulwer Island Refinery in Brisbane (Norton et al., 2008; Cameron et al., 2008). A number of different activities were developed including allowing the user to take a guided and narrated tour of CDU2, to play a game hunting for pieces of process equipment and to follow the procedure to electrically isolate an electrically-driven pump. All the activities in the environment were developed with sound pedagogical practice in mind, understanding the principles of good instructional design of education multimedia (Norton et al., 2008). Later a second learning environment was built around Coogee Energy’s natural gas-to-methanol plant in the Melbourne suburb of Laverton (Shallcross et al., 2010). This learning environment was constructed using 49 spherical images captured around the entire site. Students using the system are able to wander from the point where natural gas and oxygen lines enter the plant to the tanker loading area.

These first two learning environments may be considered as first generation systems which capture the operation of the facilities at one point in time. This paper describes the development of a second generation learning environment which will allow students to not only move around the plant in space but will also allow students to follow the construction of a processing facility over time. Students will be able to follow the sequence of construction seeing how the different engineering discipline need to work together to deliver a functioning facility.

The Water Treatment Facility

City West Water is one of three government owned water utilities in the city of Melbourne. The company sells water to residential and industrial customers in the west of Melbourne and processes the sewage from the same area. A sewage treatment facility has been in operation at City West Water’s Altona site for decades treating the sewage to a standard which allows the treated effluent to be discharged into nearby Port Philip Bay. Over recent years the site has been upgraded to a very modern facility.

For over a decade the city of Melbourne and the surrounding parts of Australia have been suffering a severe drought. Water restrictions have been put in place and Melbourne water reserves fell to just 26% in mid-2009. Three years ago City West Water took the decision to build a new water recycling facility to further process the water that was being discharged into Port Philip Bay. The new water recycling facility would use ultrafiltration and reverse osmosis technology to produce two different grades of water – irrigation water for use in the areas parks and golf courses and industrial grade water for use by heavy industry. The facility is considered world class as no other water recycling facility produces two different grades of water using a water feedstock with such a high salt content. The high salt content arises from sea water leaking into the century-old sewer pipes in the district.

The basic process employed by City West Water in their new facility is shown in simplified form in Figure 1. Water on its way to Port Phillip Bay is intercepted using an enclosed weir and is pumped into a 3000 ML holding tank. From here the water is pumped through two automatic self-cleaning filters to the four ultrafiltration units arranged in parallel. Each of these units consists of 108 vertical tubes, each of which contains thousands of hollow fibres which perform the filtration. Under pressure the water passes through the fibre walls leaving behind the contaminants including microbes which are just too big to pass through. To prevent build up of the retained contaminants the units are regularly cleaned. After leaving the four ultrafiltration units the water flows into two holding tanks before passing through a set of four cartridge filters that remove further contaminants. Next the water is pumped to
one of three reverse osmosis trains in which most of the salt is removed. This step reduces the salt content down to a level which is acceptable to the irrigation customers and a portion of this water is sent off for this purpose. The remaining water passes through two further reverse osmosis trains which removes almost all the remaining salt from the water. This water is degasified in one of two large towers before being sent to the 3000 ML product tank from which the industry partners are supplied. The reverse osmosis units also require constant cleaning and an automatic cleaning-in-place system is used to maintain the operation of the five reverse osmosis trains. The process is thus a continuous one with the ultrafiltration and reverse osmosis units operating as batch processes. As well as the main process units described above the facility also incorporates a laboratory, modern control room and the electrical room. There is an emergency back-up power generator, a neutralization pit for treating the ultrafiltration and reverse osmosis wash water and a facility for chemical dosing of the process lines.

![Simplified diagram of the City West Water water treatment facility](image)

**Figure 1**: Simplified diagram of the City West Water water treatment facility

Construction of the new facility commenced with clearing the site in December 2009. We commenced imaging the site when the main building was almost complete but before any of the process equipment had been delivered. From May 2010 until April 2011 sixteen photographic surveys were conducted around the entire site both inside the main process building and around the building.

Each spherical image is prepared by using a high-resolution 12 megapixel Nikon camera fitted with a fisheye lens. The camera is mounted on a panoramic head which in turn is mounted on a stable tripod with the camera set at eye height. The panoramic head which allows the camera to be rotated 30° in the horizontal plane about an axis through the centre of the lens. At each position seven bracketed images are taken with varying levels of exposure. Once the camera has been rotated 360° in the horizontal plane the camera is rotated through 90° so that it points directly up. The ninety-one images collected at each survey point or node are then used to generate the high resolution panoramic image. Each complete survey
involved photographing at up to 26 nodes. It was not always possible to capture every node at every visit as the site was an active construction site and the project team were instructed not to delay the construction team. Nonetheless most of the nodes were imaged during each of the 16 visits. For the final visit images at 77 different locations around the facility were recorded. This was because the team was able to access parts of the site that had been impossible to safely access during the construction period.

Construction of the facility was completed by February 2011 and the final survey of the site conducted in April captured the facility fully operational.

The Learning Environment

While the development of theory behind multimedia education lags behind the development of multimedia itself some principles have been documented on instructional design of educational multimedia (Mayer, 2003; Mayer and Moreno, 2002; Moreno and Mayer, 2000; Moreno and Mayer, 2007). These principles have subsequently been confirmed by a number of other workers, most notably Atkinson et al. (2005), Cherrett et al. (2009), Dunsworth and Atkinson (2007), Plass et al. (2003), Rasch and Schnottz (2009) and Schwan and Riempp (2004). The key aspects of the principles are summarized in Table 1.

Table 1: Principles of instructional design of education multimedia

<table>
<thead>
<tr>
<th>Principle</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple representation principle</td>
<td>Explanations in words and pictures are better than just words or pictures alone.</td>
</tr>
<tr>
<td>Contiguity principle</td>
<td>Representations of words and pictures are best presented simultaneously rather than sequentially</td>
</tr>
<tr>
<td>Coherence principle</td>
<td>The use of a few pertinent words and sounds is better than superfluous distractions.</td>
</tr>
<tr>
<td>Modality principle</td>
<td>Auditory narration alone is better than narration accompanied by on-screen text.</td>
</tr>
<tr>
<td>Redundancy principle</td>
<td>Animation and narration work better without the addition of on-screen text as well.</td>
</tr>
<tr>
<td>Spatial contiguity</td>
<td>Printed words are best placed in close proximity to their associated pictures.</td>
</tr>
<tr>
<td>Personalisation effect</td>
<td>Learning is enhanced when the lesson is presented as a conversation.</td>
</tr>
<tr>
<td>Self-referential effect</td>
<td>Learners relate better to a phenomenon or information when it is presented in first or second person, rather than in third person.</td>
</tr>
</tbody>
</table>

The above principles largely arise from cognitive load theory which provides guidelines for presenting information in a manner that does not overload the cognitive processes of the student (Sweller et al., 1998). In designing the multimedia learning environment special attention is paid to these principles to ensure that the system is appropriately designed. For example, in practice this means that a learning environment should never use a narration (audio input), an animation (visual input) and significant passages of text (verbal input). Another anecdotal principle suggests that students will relate better to an auditory narration if it is delivered by someone who sounds to be from their own age group.

Making use of the above principles the authors have developed a learning environment that allows users to move through the City West Water facility using intuitive controls. A typical
screen that the students see using the self-directed tour to explore the facility is shown in Figure 2. The view of the facility is shown in the main part of the screen. A small map of the facility is shown in the lower left corner with the available nodes indicated by circles (this image is taken from an early version of the program and does not include all the nodes currently available). A slider control at the lower right corner allows the time of the image to be selected. By clicking on the image and then dragging the cursor across the screen the view may be panned or tilted. The “shift” key is used to zoom in and the “control” key to zoom out.

Figure 2: A typical screenshot of the self-directed tour of the learning environment

An important element of the learning environment is its ability to provide descriptions of over 2000 items of equipment. By clicking on selected items of equipment detailed descriptions of the selected items are displayed in the blue box on the lower right area of screen below the right image. For example, the pump in the foreground at lower right is pump RO/CP/06C, one of the pumps used to move the cleaning solution from the two tanks in the background to one of the five reverse osmosis units. Students receive an explanation of what the individual pumps are. Students can also choose to highlight the manual butterfly valves on the intake and discharge lines to learn their functions. Each node has around 10 to 20 highlighted hotspots mapped on to them, with one node (in the electrical room) having almost 80 highlighted individual hotspots.
Figure 3 presents a sequence of four images taken from the same location within the water recycling facility. In the first image the three high pressure pumps have recently arrived and are still wrapped in the plastic used to protect them during shipping. The orange electrical conduits stand beside and in front of each pump. Three months later posts have been installed in front of each pump for the emergency stop buttons. Work has begun on assembling the intake lines into the rear of the pumps. In the background may be seen one of the two cleaning-in-place tanks and to the left the banks of reverse osmosis pressure vessels begin to appear. Immediately behind the left-most pump is a steel support which will be used to support the weight of the three discharge pipes. By December the discharge lines from each of the pumps have been installed. These lines will take the water to each of the three first pass reverse osmosis units which are to the left of the image. The pumps have been wired up and connected back to the electrical room. In the last image the facility is fully operational. The scaffolding has been cleared away as has the construction clutter. All the flow lines as well as the stop buttons have been labelled. A yellow bollard has been installed to the left of the left-most pump to protect the cabling at that point from accidental damage. In the background the cleaning-in-place system has been assembled. It should be noted that these four images have been taken to represent the sixteen surveys which have been completed at this location.
Other areas of the facility that have been imaged include the utilities areas such as the compressor room. Students often do not realize that process equipment needs to be supported by a range of utilities such as process air. How is process air prepared? What sort of equipment is necessary to provide the process air?

At the time of writing the photographic survey is complete with the detailed descriptions for over 2000 different items having been written. Short 2 to 3 minutes video sequences are being scripted and a self guided tour is in preparation.

It is planned that the learning environment will include the following elements:

- a series of 2 to 3 minute narrated video sequences following the path of the water through facility and on the batch operations of the ultrafiltration and reverse osmosis units;
- other videos discussing design decisions based around issues including the safe handling of sulphuric acid, materials selection and layout design;
- the building plans for the main structure allowing student to make the link between the plans and the structure as built;
- the process and instrumentation diagrams allowing students to link the symbols on the plans with the equipment in the plant;
- a search capability allowing users (both students and plant operators) to search through an equipment database to locate individual items of equipment out in the plant; and,
- a series of interviews with key decision-makers and design engineers addressing issues relating to the layout, design and construction of the facility.

The Way Forward

The current project is ambitious as the team seeks to develop a learning environment that will give students unprecedented access to project information and the reasoning behind important design decisions. It is our intention that students will be able to explore the projects at their own pace. Several questions remain as to how best this learning environment might be implemented in an undergraduate engineering program:

- How structured should the learning activities and objectives be that are based around the new 4-D learning environment?
- Can the learning environment be introduced at first year and then used appropriately at later year levels?
- How can learning activities be structured to address Bloom’s six levels in the cognitive domain of knowledge, comprehension, application, analysis, synthesis and evaluation?
- In what learning contexts would the 4D environment provide added insights into the complex social, economic, technical and environmental aspects of engineered systems?

Our intention with this paper is to raise awareness of the project across engineering disciplines and generate debate and ideas within industry and academe as to the further development and use of such learning tools for engineering students. As well this
environment provides an extremely valuable resource for instructors to use in a range of formal and informal classes.

We would value input from the academic, industrial and consulting communities as to how we make the project outcomes an important teaching and learning environment to help generate awareness, insight and understanding of the important aspects of the engineering life cycle for students and staff.

References


**Acknowledgements**

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Sustainable development as a threshold concept in engineering education

Lesley Sibanda¹, Jenni Case² and Harro von Blottnitz³
Department of Chemical Engineering, University of Cape Town, South Africa
¹Lesley.Sibanda@uct.ac.za, ²Jenni.Case@uct.ac.za, ³Harro.VonBlottnitz@uct.ac.za

Abstract

Sustainable development is an area of work with increasing focus and interest in engineering education. As the environmental challenges intensify, more people are realising that new approaches to development, economic activities, resource management and environmental protection are required. To face this environmental crisis, a new education is needed. Because engineering has a significant impact on the environment, it is therefore required that engineers play a crucial role in protecting the environment. In order to facilitate a better integration of sustainable development teaching within the engineering curriculum, it is essential to understand what students already know about sustainable development.

This paper presents the preliminary findings from a research project that examines if the concept of sustainable development can be conceptualised as a “threshold concept”. Threshold concepts are defined in literature as “core concepts” that act as building blocks that enable students to fully comprehend the subject. Threshold concepts are likely to be transformative, integrative, bounded, probably irreversible and potentially troublesome.

Drawing on data collected in interviews and a survey with chemical engineering students, the paper offers an initial evaluation to establish if the concept of “sustainability” fits the definition of a threshold concept. The preliminary analysis revealed evidence to suggest that the concept of sustainable development is indeed a threshold concept. The analysis also revealed that students’ learning experiences vary but that the process of learning about sustainable development is a complex and transformative experience.

Threshold concepts

Threshold concepts originated from a UK national research project, the Enhancing Teaching and Learning Environments (ETL) in Undergraduate Courses project. The research revealed that within each discipline there are some ideas that are fundamental to students “getting it”. The definition of threshold concept is given by Meyer and Land (2003) as:

A threshold concept can be considered as akin to a portal, opening up a new and previously inaccessible way of thinking about something. It represents a transformed way of understanding, or interpreting, or viewing something without which the learner cannot progress. (Meyer & Land, 2003, p. 1)

Meyer and Land (2003) further state that threshold concepts are likely to be transformative, integrative, bounded, probably irreversible and are potentially troublesome (Meyer & Land, 2003). However, it is important to note that not all threshold concepts will necessarily display all these five qualities.

Threshold concepts can be transformative, in that once acquired they may shift the way an individual views a certain subject or the world. Secondly, threshold concepts are probably irreversible as they are difficult to unlearn. Thirdly, threshold concepts are likely to be integrative. If a student has understood a threshold concept, they are more likely to integrate different aspects of the subject (Land, Cousin, Meyer, & Davies, 2005). Meyer & Land (2003) also state that a threshold concept can be bounded in that it helps define the
boundaries of a subject area. Lastly, there is a possibility that when threshold concepts exist, they may be troublesome for students.

These threshold characteristics are all closely related and interwoven. Davies and Mangan (2007) state that “a concept that integrates prior understanding is transformative as it changes a learner’s perception of their existing understanding and thus is more likely to be irreversible, because it holds together a student’s thinking about different phenomena” (Davies & Mangan, 2007, p. 712). However, the transformative nature and troublesomeness of threshold concepts may result in some students remaining stuck in an “in-between” state. This “in-between” state is referred to as a state of liminality. This notion of liminality suggests that a threshold concept is hardly ever mastered in a light bulb or single “aha” moment but rather over a period of time. Different individuals navigate the space in different ways with varying degrees of success. Meyer and Land (2008) suggest that variation may occur in three different states of liminality i.e. pre-liminal, liminal and post-liminal. The pre-liminal state involves the variation in how the learner sees the concept come into view. According to Meyer and Land (2008) the pre-liminal stage is about “how the concept is initially perceived or apprehended” (p. 3). The liminal variation involves how the “liminal space itself is entered, occupied, negotiated and made sense of, passed through or not” (Meyer & Land, 2008, p. 3). Learners will either pass through the threshold or not. During the post-liminal variation, learners are able to make knowledgeable observations and thus enter into a new conceptual space (Meyer & Land, 2008).

Methodology

The research under discussion consisted of semi-structured, one-to-one interviews with sixteen chemical engineering post-graduate students. The postgraduate students were chosen as they had been through the chemical engineering undergraduate program and it was assumed that amongst them might be those with sophisticated understandings of sustainable development. Each interview was audio taped and transcribed. The transcribed interviews constituted the data for this study. After the initial data collection, a survey was carried out to establish if the trends obtained from the interviews would be similar with undergraduate students. Participation in the project was voluntary and all participants were assured of their anonymity in participation in this research project and that no direct reference or mention of name would be made.

Does the notion of sustainable development fit the definition of a threshold concept?

This section of the findings seeks to analyse the data and ascertain if the concept of sustainable development fits the definition of a threshold concept. This was done by inspecting the interview results under the various characteristics of a threshold concept as given by Meyer and Land (2003). From the analysis conducted, it was evident that not all the respondents made statements which suggested that they had experienced all the characteristics of a threshold concept. Table 7 below gives a breakdown of how many of the respondents experienced which characteristics.

Transformative

The data analysis suggested that grasping the concept of sustainable development is indeed a transformative process. According to Meyer and Land (2003), understanding a threshold concept has the ability to shift the way a person perceives a subject. A lot of evidence was obtained that suggested that most of the respondents had experienced a change in their views and perceptions of their lifestyle, professions and life in general. This is illustrated in their everyday lifestyles and the choices the respondents make. Most of the respondents have a
new perspective on the environment and their impact. Most of the respondents discussed how they now engage in activities that minimize their carbon footprint through recycling and using public transport use. The extract below is just an example of the transformative nature of the concept of sustainable development.

I think it’s changed some of my habits as well in that I think I’m now more frugal and I tend to conserve things more and try to limit excessiveness, consumption and all that stuff.

(Allan’s interview - 28/06/210)

**Table 7. Distribution of student experiences**

<table>
<thead>
<tr>
<th>Student</th>
<th>Transformative</th>
<th>Irreversible</th>
<th>Integrative</th>
<th>Bounded</th>
<th>Trouble some</th>
<th>Liminality</th>
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<tr>
<td>Allan</td>
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<td>Harry</td>
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<td>Thando</td>
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<td>Henry</td>
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<td>Janet</td>
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<td>Grace</td>
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<td>George</td>
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<td>Portia</td>
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<td>Kagiso</td>
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<td>Pride</td>
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<tr>
<td>Patience</td>
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</table>

The data analysis also revealed that the perceptions of the respondents have changed with time. The respondent’s view of the role that chemical engineers play has evolved from thinking chemical engineering is about getting the best process to actually thinking and considering the responsibilities or the ethics behind any design.

I think that as a fresh graduate back in 2007, my idea of chemical engineering was that we design processes, we fix problems, we calculate flow, we do a lot of mathematics based stuff and at the end we come up with a process that works which is tweaked to perform optimally and that is my understanding - what was my understanding of chemical process engineering. What I failed to get at that point was the fact that we are also social capital. We have a responsibility to use the knowledge that we have for the development (I won’t say growth) of our society and we need to fulfil that responsibility. We as engineers are therefore custodians of our own natural resources, cause it’s us who designs the processes, it’s us who should consider these things so I think that as a fresh graduate as compared to now.

(Lionel’s interview – 24/06/2010)
Irreversible

The responses obtained implied that the concept of sustainable development can be irreversible in that it is unimaginable for the students to go back and think in the same light. This is perhaps evident in the changes that they make in their everyday life. The extract from Kagiso’s interview below indicates that once understood, the concept is ingrained within an individual and thus is irreversible.

I think these changes though they came as a result of restrictions, they are more long term because it has become like habits- before like I used to think about it but now I don’t anymore, it’s become like a habit that’s in me and so habits are quite hard to break.

(Kagiso’s interview – 5/10/2010)

When asked if the changes they had made were long term and permanent, all the respondents answered in the affirmative. They said it was imaginable that they would go back to their previous ways of doing things as evident in the extract below.

I don’t think I can go back because this is something that’s in me like now I can’t leave my heater on when I’m not at home and it’s only logical that I switch it off so I can’t go back and say there is enough energy so let me leave my heater on.

(Sizwe’s interview – 25/10/2010)

Integrative

The respondents’ accounts suggested that for most of them full understanding of what sustainable development is involved both theoretical and practical aspects. They acknowledge that achieving sustainable development can only be realised if the three pillars (i.e. environment, social and economic) are intertwined together. Because of their understanding of the concept, they are now able to address conceptual topics that they would not have had previously considered. The concept is integrative as it ties in with their understanding of other aspects. It also relates to the fundamental principles that they have learnt in different courses.

Essentially if you look at the plant design, sustainable development automatically comes in the form of optimising your system because by optimising your system you are reducing your energy, you are reducing your input and you are trying to reduce everything so you get your set target that you want to get out by minimising all your inputs. So sustainability also goes hand in hand I suppose with costs and optimisation so I suppose but not explicitly but implicitly it would be included in your mass balances, energy balance and so on.

(Harry’s interview – 9/06/2010)

Bounded

From the analysis, there was no data obtained that suggests that the concept of sustainable development is bounded. According to Meyer and Land (2006) this is not unexpected as threshold concepts are not necessarily bounded. This could be due to the fact the concept is multidisciplinary and thus no demarcations can made easily. This is also clear from the students’ responses that suggest that sustainable development is a complex concept that involves economic and social aspects to it.

Troublesome

There is substantial evidence that the concept of sustainable concept is troublesome in that it conflicts with the individual’s previous ideas and also involves letting go of previous comfortable positions (Meyer & Land, 2003). Because total understanding of the concept of
sustainable development involves changes in an individual’s life, it might prove troublesome for some people. This troublesome nature of the concept of sustainable development is clear in the accounts given by some of the respondents. According to these respondents, sustainable development is troublesome because whilst they have the relevant knowledge of sustainable development they are not able to implement it as this means a complete overhaul in lifestyles and choices. In her interview, Grace stated that whilst she is aware of the changes required in her life, she is not in a position to implement them. In her account, she gives examples of things she would like to implement were it possible.

I definitely think that when I’m fully in charge of my life, I will actually implement all those things. I will put light efficient bulbs, solar water heater; have a digester at home, gas cooker

(Grace’s interview – 17/06/2010)

Other respondents stated that the concept of sustainable development is troublesome because it conflicts with their personal values and future aspirations. For example one respondent states that whilst they recognize that big cars are not environmentally friendly and emit greenhouse gases, they still want to drive these cars.

I will be honest choosing between a Land Rover Discovery versus like a Mazda or something like a bicycle, I’ll go for the big car because I’m a man and the status thing but on the other hand I have to look at the environment so it’s a tough one for me.

(Kagiso’s interview – 5/10/2010)

Navigating the liminal space

Accounts of having experienced a liminal state were evident in six of the interviews. The liminal space is experienced differently by each individual and students exhibit different emotions and positions from pre-liminal state to the liminal state and finally to the post-liminal state. The interviews revealed that some of the individuals had gone through a space of uncertainty before fully comprehending the concept of sustainable development. The study also revealed that some students have difficulty changing their mindsets and adopting alternative views on development implying that they could be stuck in the liminal space. Yet for some of the respondents, it could be said that they are in the transition period as they move back and forth in the liminal space from no understanding to fragmented understanding to internalizing the threshold.

Well as I said, when I first encountered it, I think anyone who hears the term kind of has a feeling of what it is and what it involves. So you think SD and you think well that what it involves. It’s an easy concept to feel and to know but it’s a difficult concept to define.

(Thando’s interview – 11/08/2010)

However, in retrospect the respondents showed an appreciation that full understanding includes both the theoretical and the practical aspects and that sustainable development is not possible unless all the environmental, social and economic pillars are intertwined together. Some of the responses obtained suggested fragmented understanding. Here the students have begun to grasp the severity of the situation but do not yet have a complete viewpoint. Whilst students in this phase demonstrate knowledge of more relevant facts, they are unable to relate the facts to each other and sometimes students feel that certain aspects of sustainable development are more serious than others.

Like I mentioned before it’s like you kind of know that ‘oh it would be nice to separate plastics from food waste for example and yet today I still don’t do it. I put rubbish in one bin and I couldn’t care less where it’s going so it can’t be 100% and it means I’m not living a fully sustainable life. But I know that for example if
I was working for a company and I was involved in design because I think also it’s a mindset like if I get back to the issue of global warming that is more serious to me than making a few landfills because you don’t at this stage really see the effects, you don’t feel the effects. I know this rubbish is going to landfills and cause pollution and methane production which also has an effect on the environment and yet because global warming is a bigger issue today. I find myself considering that to be more important than just a landfill you know so I think it’s a mindset, a very bad one.

(Portia’s interview – 23/08/2010)

The analysis also showed that there was no lack of emotional reactions while trying to grasp the concept of sustainable development. Most of the respondents exhibit strong feelings which range from boredom, frustration, fear, hate and euphoria. This was expected as Meyer and Land infer that liminal spaces are unsettling, problematic and humbling.

**Discussion and Conclusion**

The data analysis suggests that there is evidence to suggest that the concept of sustainable development is a threshold concept. The analysis revealed that students’ learning experiences vary but that the learning process of sustainable development as a concept is complex and is a transformative experience. From the research finding, it is evident that sustainable development is transformative, integrative, irreversible and troublesome. Sustainable development is an integrative concept. This implies that sustainable development is about taking disparate and seemingly unrelated elements together in an attempt to create a cohesive whole. This also implies that sustainable development is a continuous process that requires engineers to constantly reassess their actions allowing for adaptability of their solutions to specific contexts. There was no evidence from the data analysis that the concept of sustainable development is bounded. This is expected as not all threshold concepts are bounded, this is consistent with the work of Meyer and Land (2003) who state that threshold concepts are “possibly often (though not necessarily always) bounded” (p. 6). In the case of sustainable development, the characteristics of bounded cannot apply as the concept is multidisciplinary and therefore the boundaries of the concept cannot be defined.

In the interviews, most of the students expressed varying opinions towards the future in relation to sustainable development challenges. A few of the respondents were optimistic but the majority had pessimistic viewpoints. In their discussions, there is a sense of frustration, anxiety and sadness about the environmental crisis and the challenges that have arisen as a result of unsustainable practices. These findings are consistent with the literature on threshold concepts. According to Eckerdal *et al* (2006), students often exhibit emotional reactions while learning threshold concepts. These feelings range from fear, hatred, frustration, depression and euphoria at finally grasping the concepts (Eckerdal, *et al.*, 2006). Kagawa (2007) also states that it is common for students to express these negative feelings and states that this has significant implication for engineering education. According to Kagawa (2007), traditional engineering education does not take into account the “emotional impacts of global issues on students and thus it is imperative to develop pedagogies that provide hope, liberation and empowerment to students” (p. 334).

The study also examined the notion of liminality. It is clear that the process of understanding sustainable development is complex and sometimes difficult for students. The learning experience for each student varies as each student navigates the liminal space differently. Because of this, teaching of sustainable development should accommodate each individual student. However characterizing sustainable development as a threshold concept raises the questions:

How can threshold concepts be used as a framework for learning?
Can the liminal space be a useful way to determine how students understand sustainable development?

Taking into account the research findings, it is evident that there is a need for a transformation within the engineering education sector. If engineers are to make a significant contribution to sustainable development, it is essential that sustainable development becomes a fundamental part of engineering education curricula. This implies that the concept of sustainable development cannot be a mere “add-on” to the curricula but rather be a core part of the curriculum. Therefore sustainable development should be taught in a way that students can relate to on a personal level. Incorporating sustainable development into the curricula in earlier stages encourages students to always think with sustainable development in mind and therefore students use sustainable development as a framework for engineering practice. The threshold concept theory provides a new way of looking at the learning of sustainable development. It provides a foundation for successful development of curricula and therefore maximises the teaching and learning experience of a concept. However, more research needs to be conducted to determine how best to integrate sustainable development as a threshold concept in engineering education.

References


Full Paper

Literacy across the Curriculum in the Engineering Sciences: A Case Study of a Course in Concrete Technology

Zach Simpson¹ and Jannes Bester²
¹Engineering Education, University of Johannesburg, South Africa; ²Department of Civil Engineering Science, University of Johannesburg, South Africa
¹zsimpson@uj.ac.za, ²jannesb@uj.ac.za

Abstract

Engagement with engineering professionals on the part of the authors has, at times, yielded dissatisfaction with the quality of engineering graduates, particularly with respect to verbal and written communication abilities. It is thus clear that engineering curricula must do more to develop these abilities more overtly within engineering degree and diploma programmes. To this end, the development of academic literacies (reading, writing, critical thinking and speaking) must be incorporated into engineering content modules. This requires the development of literacy across the curriculum.

This paper analyses the literacies embedded in one particular module offered as part of the degree in Civil Engineering Science at the University of Johannesburg, namely Concrete Technology. The analysis is undertaken using a two-pronged methodology. First, a quantitative analysis of the stated outcomes and assessments given in the course is undertaken in terms of Biggs’ SOLO taxonomy. Thereafter, a qualitative description of the module within the framework of nine central literacy practices required of engineering graduates in South Africa is given.

The aim of this analysis is to understand the literacy practices currently embedded within the course so as to identify the areas in which the course can further develop students’ academic literacies. Biggs’ SOLO taxonomy is used as it provides an easy to use (and understand) means of measuring a) the extent to which higher order cognitive demands are being placed on students and b) the degree of alignment between the modules stated outcomes and the assessments given. This paper works from the assumption that a clear understanding of current practice within individual courses is necessary prior to the implementation of literacy across the curriculum. This is to ensure that individual courses within engineering degree and diploma programmes scaffold students’ participation in the literacy practices of the various engineering sub-disciplines.

Introduction

An external examiner of our final year Civil Engineering students’ research project reports wrote in her examination report, that certain skills “need to be developed in the students in order to more satisfactorily achieve the ECSA [Engineering Council of South Africa] outcomes”. The examiner went on to list and discuss these skills as follows: grammatical, spelling and punctuation errors, appropriate style of writing for the target audience, document layout, logical argument and appropriate use and integration of graphical content. The examiner also wrote of the importance of students being “coached in the concept of a ‘golden thread’ ... that ties each section in the report to all those that precede or follow it”, and elaborated that “each part of the project fits together ... to form a complete picture”.

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This concern with appropriate written communicative competencies is echoed by many engineering professionals, who argue that while graduates may possess the technical skills and know-how to be competent engineers in practice, they often lack competence in professional written and verbal communication. Such competence offers engineering graduates a competitive edge in the workplace and assists them in attaining leadership positions. It is thus imperative that engineering degree programmes offer students opportunities to master the literacies required of them during study and after graduation.

According to Boughey (2002; 2007), academic development efforts have often adopted a deficit approach and have focused on so-called underprepared or non-traditional students. However, most, if not all, engineering students need practice in the particular literacy practices employed within the Engineering sciences. Previous models of addressing this matter have included the development of stand-alone ‘communication’ or ‘literacy’ courses (Kloot, Case and Marshall, 2008). However, in order to overcome the shortcomings of these courses, the idea of literacy across the curriculum has become popular. This involves embedding the use and development of literacy practices within the context of mainstream or core disciplinary content (Davidowitz, 2004). Within the context of Engineering at the University of Johannesburg, where literacy across the curriculum has not been implemented to any real degree, it has become necessary to first analyse what is ‘going on’ in individual courses, by way of literacy practice, before steps can be taken to enhance the development of student literacies within those courses.

In this paper, we analyse the literacy practices embedded in a particular course offered as part of the degree in Civil Engineering Science at the University of Johannesburg, namely Concrete Technology. Concrete Technology is offered at second year level and is one of the first ‘proper’ engineering courses in the degree (the first two years of the engineering degree programmes largely consist of courses in mathematics and physical science offered by the Faculty of Science). Because of its early appearance in the programme and because students have engaged in little literacy practice prior to entering the course, it is an ideal vehicle for the incorporation of literacy development. To this end, below, we discuss the methodology used to analyse the Concrete Technology course and use this methodology to discuss ways in which the course can be amended to include more in the way of focused literacy development within the course content.

**Biggs’ SOLO taxonomy**

Because Biggs’ Structure of the Observed Learning Outcome (SOLO) taxonomy (Biggs, 2003) is used extensively in the work described in this paper and because it may not be familiar to all readers, it is necessary to provide a brief explanation of this taxonomy. Those readers already familiar with the taxonomy may want to skip this section.

Biggs’ SOLO taxonomy consists of five levels. The first of these is prestructural understanding where students demonstrate little or no understanding. Students at the next level, unistructural understanding, are able to understand terminology and little else. Students at a multistructural level understand concepts but can only knowledge-tell and cannot relate parts to a whole or apply knowledge across contexts. The penultimate level of understanding on the SOLO taxonomy is relational understanding, where students can do more than simply list facts; they can apply and relate knowledge across contexts. Finally, at an extended abstract level of understanding, students are able to engage in high-level conceptualization, abstraction, hypothesis-generation and theorization.
The first three levels of the SOLO taxonomy represent a quantitative phase where students understand more or less. However, the last two levels of the taxonomy represent a qualitative phase where students engage with course content in qualitatively different ways. Thus, as students move across Biggs’ SOLO taxonomy, they must first increase their knowledge (quantitatively) and then deepen their understanding (qualitatively) (Biggs, 2003: 41). Essentially, the SOLO taxonomy allows us to understand that the development of students as readers, writers and critical thinkers requires a shift away from outcomes and assessments that represent a low level of understanding towards higher-order cognitive demand.

**Analysis: Literacy practices embedded in Concrete Technology**

Figure 1 depicts the methodology employed in understanding the literacy practices embedded in the Concrete Technology course. In this section, we present our analysis of the Concrete Technology course in terms of this methodology. We stop short of offering any interpretation or discussion of the findings of the analysis in this section. Instead, such interpretation and discussion is reserved for the section that follows. As is indicated in the figure, the point of departure was to analyse the module outcomes in terms of the level of cognitive demand they require from students. In total, eight outcomes are listed for the Concrete Technology course. These are depicted in Table 1.

![Figure 1. Diagrammatic depiction of methodology](image)

From Table 1, it is evident that the outcomes listed for the Concrete Technology course are pitched at an advanced level of cognitive demand. That is to say, each one of them requires students to demonstrate an ability to do something with the knowledge they have gained in the course, rather than simply reproduce that content. The outcomes therefore suggest a qualitatively deeper understanding of the module content.

The next step in the analysis required an investigation into the assessment opportunities provided for in the course. To allow for comparison, Biggs’ SOLO taxonomy was used again. Assessment in the Concrete Technology course consists of one practical (lab) report and three semester tests (as well as a further sick test), as well as a final, summative examination. Table 2 indicates the relative weighting of these respective assessments.
Table 1. Outcomes of Concrete Technology classified according to SOLO taxonomy

<table>
<thead>
<tr>
<th>#</th>
<th>Outcome</th>
<th>SOLO Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Apply basic scientific fundamental knowledge to properties of concrete in fresh and hardened state</td>
<td>Relational</td>
</tr>
<tr>
<td>2</td>
<td>Apply scientific fundamental and specialist knowledge to concrete constituents: cement aggregates, admixtures and additives</td>
<td>Relational</td>
</tr>
<tr>
<td>3</td>
<td>Design a proper concrete mix for durable concrete</td>
<td>Extended abstract</td>
</tr>
<tr>
<td>4</td>
<td>Apply basic scientific fundamental knowledge as well as specialised knowledge of properties of fresh concrete, to formwork for concreting and various architectural finishes</td>
<td>Relational</td>
</tr>
<tr>
<td>5</td>
<td>Plan and conduct investigations and experiments, using diagnostic procedures and appropriate equipment, to analyse concrete degradation and propose a repair or rehabilitation plan for these concrete structures</td>
<td>Extended abstract</td>
</tr>
<tr>
<td>6</td>
<td>Apply knowledge of physical laws to the methods of transporting and placing concrete</td>
<td>Relational</td>
</tr>
<tr>
<td>7</td>
<td>Apply scientific fundamental and specialist knowledge to production processes</td>
<td>Relational</td>
</tr>
<tr>
<td>8</td>
<td>Apply knowledge of basic sciences and specialised knowledge to concreting under hot and cold weather conditions</td>
<td>Relational</td>
</tr>
</tbody>
</table>

Table 2. Assessments in Concrete Technology

<table>
<thead>
<tr>
<th>Assessment Methodology</th>
<th>Weighting</th>
</tr>
</thead>
<tbody>
<tr>
<td>Semester tests (x 4)</td>
<td>30%</td>
</tr>
<tr>
<td>Practical (lab) report</td>
<td>20%</td>
</tr>
<tr>
<td>Examination</td>
<td>50%</td>
</tr>
</tbody>
</table>

Table 3 summarizes the level of cognitive demand (according to the SOLO taxonomy) in the Concrete Technology course. As can be seen in Table 3, some questions in the tests and exam required the performance of calculations or sketching of illustrations. Because the focus of the analysis was on reading, writing and critical thinking, it was decided to separate these questions out from the main analysis. However, it should be noted that these questions generally require the application of content knowledge and are therefore likely to require relational understanding. Furthermore, it is important to note that quantitative literacy and multimodal literacy are both, of course, extremely important literacies within engineering.

As can also be seen in Table 3, each of the four tests is weighted at 7.5% of the overall mark for the course. Each test is actually weighted at 10% and students would in fact only write three of the four tests. However, in order to maintain proportion in the analysis, it was
decided to scale down the weighting for the tests. Furthermore, for the purpose of the analysis, the practical (lab) report was classified as requiring relational understanding as it demanded of students to understand the effects of certain variables on the properties of fresh and hardened concrete. It was decided not to classify it as extended abstract because it stopped short of requiring students to generate arguments or propose recommendations based on the lab test results. As a final note, the last column in the table represents the total proportion of the course assessment which requires each type of assessment as classified according to the SOLO taxonomy. This proportion takes into account the relative weighting of each assessment opportunity.

Table 3. Classification of Concrete Technology assessments according to SOLO taxonomy

<table>
<thead>
<tr>
<th>SOLO Classification</th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Sick test</th>
<th>Practical (lab) report</th>
<th>Exam</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Marks</td>
<td>50</td>
<td>50</td>
<td>40</td>
<td>60</td>
<td>100</td>
<td>100</td>
<td>400</td>
</tr>
<tr>
<td>Weighting</td>
<td>7.5%</td>
<td>7.5%</td>
<td>7.5%</td>
<td>7.5%</td>
<td>20</td>
<td>50</td>
<td>100</td>
</tr>
<tr>
<td>Prestructural</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Unistructural</td>
<td>6%</td>
<td>14%</td>
<td>0%</td>
<td>0%</td>
<td>0%</td>
<td>4%</td>
<td>3.5%</td>
</tr>
<tr>
<td>Multistructural</td>
<td>18%</td>
<td>50%</td>
<td>57.5%</td>
<td>40%</td>
<td>0%</td>
<td>21%</td>
<td>22.9%</td>
</tr>
<tr>
<td>Relational</td>
<td>48%</td>
<td>26%</td>
<td>25%</td>
<td>20%</td>
<td>100%</td>
<td>8%</td>
<td>32.9%</td>
</tr>
<tr>
<td>Extended abstract</td>
<td>0%</td>
<td>10%</td>
<td>0%</td>
<td>6.7%</td>
<td>0%</td>
<td>6%</td>
<td>4.3%</td>
</tr>
<tr>
<td>Calculations / Illustrations</td>
<td>/</td>
<td>28%</td>
<td>0%</td>
<td>17.5%</td>
<td>33.3%</td>
<td>0%</td>
<td>61%</td>
</tr>
</tbody>
</table>

As can be seen, approximately 37% of the course assessment requires relational or extended abstract understanding of the course material, while another 36% requires students to perform calculations or sketch illustrations. The remainder of the course assessment requires reproduction of information given in lectures or in the textbook. That is, about 26% of the course assessment requires unistructural or multistructural understanding of course content.

The second, and final, aspect of our analysis involved a qualitative description of the module in terms of nine central literacy practices required of engineering students upon graduation. These literacy practices are discussed in detail in a previous paper (Simpson and van Ryneveld, 2010). Table 4 summarizes these central literacy practices and indicates which ones are practised in Concrete Technology.
Table 4. Assessment of Concrete Technology according to central literacy practices identified in Simpson and van Ryneveld (2010)

<table>
<thead>
<tr>
<th>Category</th>
<th>Literacy Practice</th>
<th>Practiced in Concrete Technology?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reading</td>
<td>reading across multiple text types and disciplines</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>discerning essential (or relevant) from non-essential (or irrelevant) information</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>comprehending, summarising, paraphrasing, synthesising and referencing information from other sources</td>
<td>N</td>
</tr>
<tr>
<td>Writing</td>
<td>language competence</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>audience-awareness</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>purpose-awareness (or text-type awareness)</td>
<td>N</td>
</tr>
<tr>
<td>Critical</td>
<td>argument, evaluation and reasoning</td>
<td>N</td>
</tr>
<tr>
<td>Thinking</td>
<td>reflection and independent learning</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>relational and analytical thinking (or the ability to apply knowledge)</td>
<td>To Some Extent</td>
</tr>
</tbody>
</table>

In terms of our analysis, it can be seen that the Concrete Technology course, as it stands, does not offer students opportunities to practice many of the key literacy practices needed at graduation. One practice that is incorporated into the course is language competence. Because it is built into the assessment rubric for the lab reports, students are made aware of the need for linguistic accuracy in their technical report writing. In addition, as indicated in the quantitative analysis, the outcomes and assessments in the course place emphasis on relational and analytical thinking. However, whereas the outcomes suggest that such relational thinking constitutes the bulk of the course, the assessments place relatively less importance on this. It is for this reason that our finding is that relational thinking is practiced to some extent in the Concrete Technology course.

Discussion: Implementing Literacy Development within Concrete Technology

The goal of the above analysis of the Concrete Technology course is to provide a clear understanding of current practice within this course. Such an understanding of individual courses is necessary prior to the implementation of literacy across the curriculum. This is to ensure, in line with social constructivist principles, that individual courses within engineering degree and diploma programmes scaffold students’ participation in the literacy practices of the various engineering sub-disciplines. To this end, three factors bear consideration with regard to developing the Concrete Technology course so that it better contributes to the development of student academic literacies.

First, attention needs to be paid to how the Concrete Technology course interacts with parallel, preceding and succeeding modules in the curriculum so that students’ mastery of academic literacy practices is adequately scaffolded. Second, given its location within the overall programme, decisions must be made about which literacy practices should be focused upon within the Concrete Technology module as well as what degree of cognitive demand is appropriate for this module. Finally, investigation should be undertaken into aspects of
writing intensive teaching that may be implemented within the context of the Concrete Technology module.

Each of these three points is discussed below.

**Concrete Technology and the Civil Engineering Science degree programme**

Attempts at reforming engineering education can occur at a number of levels; these include the level of the individual course and whole programme level (Crawley, Malmqvist, Ostlund and Brodeur, 2007). In this paper, we focus our discussion at the level of the individual course. However, we further argue that the development of student literacies must occur throughout our engineering degree programmes. As such, the development of a course such as Concrete Technology must be seen as just a beginning of a much larger initiative aimed at programme reform. Concrete Technology is a useful point of departure for our purposes as the structure of the Civil Engineering Science degree is such that the first year and a half is dominated by Mathematics and Physics courses. Concrete Technology is among the first ‘engineering’ courses that students encounter in their degree studies. Because of its relatively early placement in the curriculum, Concrete Technology must act as a springboard from which students’ literacy development can be enhanced in the courses or modules that follow it in the curriculum.

Such scaffolding of student academic literacy development is in line with much of the recent literature on the subject. For example, Paxton (2007) argues that students are in a process of ‘interim literacy’ as they master the literacy practices of their chosen discipline. The notion of interim literacies forces universities to acknowledge that these practices need to be mediated through degree programmes. Paxton’s argument is similar to that of Jacobs (2007) who argues that the development of academic literacy is not something that can be undertaken at first year level only; instead, it occurs over the course of the entire undergraduate degree and should in fact be seen as one of the goals of a degree programme. Furthermore, Kloot, Case and Marshall (2008) argue that development of mainstream university curricula should not be limited to first year but should be infused into all years of study. It is clear then that scaffolding of student literacy development should take place such that it achieves the aim of creating a “coherent curriculum in which all courses have well-defined and interconnected roles in achieving the programme mission” (Felder and Brent, 2002).

An example of the integration of student academic literacy development within and across university modules has been offered by Crawley et al (2007) at Chalmers University of Technology in Sweden. In this example, the authors illustrate how a number of courses within a Mechanical Engineering degree programme work in tandem to develop students’ written and oral communicative competence. For example, a course at first year requires students to write a technical report and deliver an oral presentation. The course provides students with input into how to write technical reports, how to deliver effective oral presentations and how to incorporate multimedia, amongst other topics. In addition, discussion around these issues is promoted in class. These abilities are then practiced in later courses where further aspects such as critical thinking and poster production are introduced. The courses thus build up in complexity until the final year thesis requires students to put into practice all of the abilities developed during the course of the programme.

While the example given here may resemble what happens in countless other programmes, the fact that it is undertaken systematically and explicitly is important. The value of the Concrete Technology course within the larger Civil Engineering Science programme must be
similarly systematically and explicitly described in terms of its contribution to the development of student academic literacies. It is to this point that the following subsection turns.

**Which literacy practices and what level of demand?**

According to Evers, Rush and Berdrow (1998), the development of student competence requires curricular reform such that each course makes a contribution to the goals of the program. They further argue that this can be undertaken through the analysis of specific courses according to a matrix of competencies. To return to the list of literacy practices discussed above that were posited by Simpson and van Ryneveld (2010), this would require decisions to be made around which of the nine literacy practices ought to be focused upon within Concrete Technology. Because of its relatively early placement in the curriculum, it may be prudent to focus on the reading and writing practices in this course and leave the critical thinking practices to courses later in the programme. It is important to note that no one course need cover all the literacy practices; instead, they should be covered across the sum of the courses (Evers et al, 1998).

In addition to decisions around which literacy practices should be incorporated into the Concrete Technology course, decisions must also be made with regard to the level of cognitive demand placed on students within the course. This is important as, in order to benchmark program effectiveness, objectives should be explicit about how students should perform at key milestones and at graduation (Mentkowski and Associates, 2000). To this end, Biggs’ (2003) levels of student engagement with course content are helpful. Biggs’ levels are depicted in Figure 2 and range from low-level to high-level engagement.

![Figure 2. Biggs’ Levels of Engagement with Course Content (Biggs, 2003)](image)

According to Biggs (2003), good teaching involves getting students to use the higher level processes (such as theorizing and applying). However, as with the question of which literacy practices ought to be covered, not every course need require such high-level engagement. For example, it may be sufficient for a course at second year level, such as Concrete Technology, to move as far up the ladder of engagement as ‘relating’ without going any further. This is because students need to be given the opportunity to master simpler tasks before moving on to more complex ones. The importance of this is well-illustrated in James Gee’s 2003 study of children’s learning of video games. In this study, Gee argues that people need to be introduced to problems in carefully selected orders; problems that are too complex and presented too early do not promote effective learning. In addition, as Gee argues, good games create expertise by giving players multiple opportunities to practice skills until they are mastered before new skills are required; these new skills are then integrated with and developed from the old, mastered skills.
Writing intensive teaching

The following quotation is taken from the minutes of a meeting of the American Society of Engineering Education held in 1897, more than a century ago:

My practice … was to take as a reading book for the class in chemistry in the Junior year a well-known German periodical of analytical chemistry after the class had had one year of preparation in German grammar and in simple reading exercises. The students were generally appalled at the idea that they were expected to read a work of this character after (as they thought) so slight a preparation, and they were astonished to find in the course of a few weeks that the exercise had lost all terror for them. After a few hours in the class room, in which I found out how much they knew about the construction of German sentences, I began to discuss with them the subject-matter of the articles we were reading. By selecting subjects with which they were more or less familiar, and operations which some of the members of the class were, perhaps, working on in the laboratory, the exercise became a chemical conference on recent German literature. By holding to this idea throughout the remainder of the year the students lost sight of the language in the matter, and during the Senior year there were very few students of chemistry who did not consult German books in the library with ease and confidence.

(American Society for Engineering Education, 1897: 252 – 253)

This testimony illustrates the importance of the development of student literacy (in this case literacy in German) within the context of course content. Like the engineers-in-training in 1897 who needed fluency in a foreign language, many of our students today are studying engineering in a language with which they do not necessarily have full familiarity. Even those students who are fully conversant in English may well struggle due to the highly technical and specialized language of engineering. As such the development of written communicative competence must be developed within engineering courses. This requires the implementation of writing-intensive teaching.

As Evers et al (1998) argue, lecturers must grade not only content but also oral or written presentation of that content as there is little point in focusing on content if the communication of that content prevents its comprehension and communication. This argument is supported by Sulcas and English (2010) who argue that the work of the engineer requires advanced communication skills and it is therefore important for universities to equip students with the ability to communicate effectively across professions. As mentioned above, this relies on scaffolding students’ participation in the literacy practices of the engineering profession.

According to Kalman (2008), scaffolding implies that activities need to be designed in order to nurture the growth of students’ intellectual development. Kalman (2008) continues that a number of factors hinder student learning in science and engineering which can be overcome through an approach to scaffolding that includes a variety of interventions in the classroom. This is in accordance with Biggs’ (2003) argument that successful teaching for learning ought to be concerned with what students do during learning rather than with what teachers do. One of the ways of scaffolding student learning is to encourage students to engage in reflective writing (Kalman, 2008).

Writing is not only a valuable tool for communication, but it can also be used to assist student learning (Young, 1999). Writing to learn is a technique that assists students in meeting expectations with regard to higher-order thinking as it helps them to apply and internalize the importance of what they have learnt rather than simply memorize information (Kalman, 2008). Such reflective writing tasks, however, should not require students to merely summarize what has been covered in the textbooks or lectures; instead, it should require them to establish connections and build their knowledge (Kalman, 2008).
A Practical Example

The above discussion has demonstrated, rather theoretically, the need for reform within the Concrete Technology course, not because the course is problematic, weak, poor or wrong, but because there is a need for more focused, explicit and systematic development of student academic literacies within the curriculum and Concrete Technology was identified as one of the courses which lend themselves to such development. In the paragraphs that follow, we now describe, in more practical terms, some of the changes that are being introduced to the Concrete Technology course.

The first significant change to the course is the incorporation of a literature review report on a topic of the students’ choosing. Such a project will provide students with the opportunity to practice the key reading practices of discerning essential from non-essential information and the ability to read, paraphrase, integrate and synthesise information from other sources. However, because this, in most instances, will be the first time students are expected to engage in these kinds of activities, the decision was also made to incorporate the development of these abilities into the course content. To this end, the decision was made to include a class that provides focused input on synthesis and integration of sources as well as on avoiding plagiarism. Such a class would aim to prepare students for the submission of the literature review reports.

A second change made to the course pertains to the lab report. Prior to this project, Concrete Technology students were required to produce one fairly large lab report at the end of the semester. However, the decision was taken to now include three shorter lab reports spaced throughout the semester so that students are able to receive feedback on and in turn improve their lab report writing during the semester. In addition, it was also decided to assess these lab reports, in part, against an assessment checklist that clearly details the expectations of a successful scientific lab report. In this way, students would be able to rather clearly identify the ways in which their future lab reports need improvement.

Thirdly, the tests in the Concrete Technology course were revised such that the first test focuses on rather lower-order concerns of understanding course content whereas the second test then requires of students to engage in the higher-order engagement activities of analysis, evaluation and application.

Finally, it was also seen as important to look at classroom practice within the course. To this end, it was decided to re-structure lectures to include more demonstration and discussion of the application of the theory of Concrete Technology.

The changes described in this section, we would argue, have the potential to dramatically improve student learning within the course and will go some way towards giving students the required practice with the reading, writing and critical thinking practices they need to master for the rest of their studies and for their working life. However, attention needs also to be given to how other courses within the programme also contribute to students’ academic literacy development. Furthermore, the implementation of these changes needs to be tracked so that the impact thereof can be clearly studied to ensure that they achieve their intended goals.

Conclusion

It is important to note that the Concrete Technology course, as it stands, is not dissimilar from any number of other university courses in South Africa and abroad. As such, the point of this paper is not to argue that there is anything ‘wrong’ with the course or that it is ‘weak’,

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‘inappropriate’ or ‘bad’. However, if our students lack the communicative competence they need upon graduation, as engineering educators, we need to revise our approach and ‘do things differently’. To this end, the argument present in this paper is best summarised as follows:

1) Engineering students often struggle with the literacy challenges they are faced with during the course of their study.

2) The development of student literacies not only better prepares students for the world of work; it also assists them in learning the content of their various engineering courses.

3) Therefore, an analysis was undertaken of the literacy practices currently embedded within a course on Concrete Technology so as to identify the areas in which the course can further develop students’ academic literacies.

4) This analysis was two-pronged. First, Biggs’ SOLO taxonomy was used to examine the extent to which higher order cognitive demands are being placed on students and the degree of alignment between the modules stated outcomes and the assessments given. Second, a qualitative analysis of the course in the context of key literacy practices evident in documentation from the Engineering Council of South Africa was undertaken.

5) The results of the analysis reveal that the outcomes suggest that a qualitatively ‘deep’ understanding of the module content is required while a sizeable portion of the course assessments require relational or extended abstract understanding of the course material; in addition, within the context of key literacy practices evident in documentation from the Engineering Council of South Africa, it can be seen that the Concrete Technology course offers students opportunities to practice some of the literacy practices required at graduation and beyond.

6) The paper concludes that a clear understanding of current practice within individual courses is necessary. This is to ensure, in line with social constructivist principles, that individual courses within engineering degree and diploma programmes scaffold students’ participation in the literacy practices of the various engineering sub-disciplines.

7) Three recommendations are made with regard to developing the Concrete Technology course so that it better contributes to the development of student academic literacies.
   a. First, decisions must be made about which literacy practices should be focused upon within the Concrete Technology module as well as what degree of cognitive demand is appropriate for this module given its location within the overall programme.
   b. Second, attention needs to be paid to how the Concrete Technology interacts with parallel, preceding and succeeding modules in the curriculum so that students’ mastery of academic literacy practices is adequately scaffolded.
   c. Finally, the paper discusses aspects of writing intensive teaching that may be implemented within the context of the Concrete Technology module.
References


Assessing ECSA Outcomes Using a Portfolio Approach: Achievements and Lessons Learnt

Jeff Smithers¹ and Louis Lagrange²
School of Bioresources Engineering and Environmental Hydrology, University of KwaZulu-Natal, South Africa
¹smithers@ukzn.ac.za, ²lagrangel@ukzn.ac.za

Abstract
The Engineering Council of South Africa (ECSA) and many international accrediting bodies of engineering programmes require that all graduates from accredited engineering degrees are competent at generic exit level outcomes. The accrediting bodies generally do not stipulate how to assess the outcomes and different approaches have been reported in the literature to assess the outcomes and the use of student portfolios is being increasingly used. Different approaches have been adopted in the assessment of the outcomes required by ECSA by the various engineering disciplines at the University of KwaZulu-Natal (UKZN). Frequently these are linked to selected module assessments. The Agricultural Engineering discipline at UKZN has for the past four years required students to compile a portfolio of evidence of their competence in the ten ECSA outcomes. This paper contains a brief review of the assessment of engineering outcomes to meet accreditation requirements and also provides some detail on the ECSA portfolio used in the Agricultural Engineering discipline at UKZN, including some discussion of what has worked and also the challenges which still remain.

Introduction
Design, effective teaching, computer technology, broad based curriculum and accreditation/assessment were identified as the most significant challenges to engineering education from interviews of 27 national leaders in engineering education in the USA (Bjorklund & Colbeck, 2001). In particular, the assessment of student competency at outcomes specified by the Accreditation Board for Engineering and Technology (ABET) in the USA were noted as a major challenge at the time. As a consequence of the ABET accreditation criteria, engineering programmes in the USA are moving from an “input” coursework completion to an “output” focus on student competency in specified outcomes (Brumm et al., 2006). Brumm et al. (2006) define competencies as the “application of behaviour and motivation to knowledge, understanding and skill” and are measured through actions or demonstrations by a student. The focus is thus on what graduates can do with what they have learnt and not solely on the learning of a skill or on knowledge gained (Brumm et al., 2006). The assessment of outcomes sets and measures clear goals and thus improves learning while iteratively improving the programme (Heinricher et al., 2002).

Changes to engineering curricula in South Africa were driven by the creation of bridging programmes in the later 1980’s and early 1990’s (Jawitz et al., 2001). The adoption of an outcomes based approach to accreditation of university engineering programmes in 1998 by the Engineering Council of South Africa (ECSA), in line with the Washington Accord which include signatory countries like the USA, UK, Australia and Canada (Case & Collier-Reed, 2010), has resulted in a second wave of curriculum review which has created opportunities for substantial curriculum development (Jawitz et al., 2001). Jawitz (2001) elaborated on the opportunities created as follows:
“It has brought key educational issues, namely the relationship between learning objectives, the learning process and assessment, to the fore for discussion in engineering departments.

It allows much greater freedom for programmes to define their own content as the emphasis has shifted from what students know to how students can use what they know.

It is focusing attention on how we assess our students.

It requires that our programmes have in place systems of continuous evaluation and improvement, a healthy change from the ad-hoc approach that we currently depend on, and one that will force us to apply in our educational design the same principles that we teach our students to adopt in their engineering design”.

ECSA, as the accrediting body for engineering programmes in South Africa, have also included “Assessment of Exit Level Outcomes” as one of five criteria used to accredit engineering programmes (ECSA, 2008). In order to assess student competence in the ten specified generic engineering outcomes, ECSA require that the assessment process within the programme must:

(i) “ensure that all graduates satisfy each exit level outcome defined in the relevant standard;
(ii) use a documented set of assessment criteria and processes that, taken together, demonstrate that the outcomes are satisfied at the level indicated by the range statement; and
(iii) use appropriate policies and procedures to validate assessment through internal and external moderation of assessment tasks by appropriately qualified and experienced personnel” (ECSA, 2008).

Specified assessment criteria and range statements are provided for each of the outcomes (ECSA, 2004), but engineering programmes are allowed to use alternative criteria to demonstrate achievement of the learning outcomes at the specified level (Case & Collier-Reed, 2010; ECSA, 2008). However, ECSA does not specify the types of evidence which may be used to assess the outcomes and this is left to the discretion of the university. It is also important to note that ECSA require that all graduates are competent in all the exit level outcomes and hence assessment of the competence of each student is necessary.

Trends in International Accreditation

According to Jawitz et al. (2001), the widely adopted assessment of outcomes has replaced the traditional accreditation criteria which focussed on content and process of education which assumed that the process resulted in the required outcomes. The adoption of outcomes based assessment has been driven primarily by employers who require engineering graduates to have a sound core of fundamental knowledge in mathematics, the basic sciences and engineering sciences with some specialist knowledge, coupled with the attitudes and abilities to support lifelong learning and the assessment of outcomes is seen as the most effective way of achieving these requirements (Jawitz et al., 2001). It remains to be seen how closely the attributes required by industry and the accreditation body match those viewed as important by engineering educators (Case & Collier-Reed, 2010).

The generic outcomes adopted by ECSA and a number of accrediting bodies include the following (ECSA, 2004; Jawitz et al., 2001):
(i) The ability to solve complex problems.
(ii) The ability to analyse artifacts, systems and situations.
(iii) The ability to design using a systematic approach.
(iv) The ability to plan and conduct investigations and to analyse data.
(v) The ability to select, use and evaluate the result of engineering methods and computational tools.
(vi) The ability to communicate orally and in writing with peers, other professionals and lay audiences.
(vii) The ability to assess the impact of engineering activity on society, the economy and the environment.
(viii) The ability to work effectively in a team situation and across disciplinary boundaries.
(ix) The ability to learn independently.
(x) A critical awareness of the professional responsibilities of the engineer.

Jawitz et al. (2001) highlight the difficulty in showing how the outcomes are developed within an engineering programme and the assessment of the outcomes. Brumm et al. (2006) believe that the outcomes represent a collection of competencies required in the workplace and are too complex to measure directly. According to McNair et al. (2006), assessment criteria and assessment tools are available to confidently assess the technical outcomes, but the professional outcomes listed above are more challenging to assess.

Similar to other accrediting bodies, ECSA specifies the outcomes the engineering programme as a whole must achieve, but does not specify how to do this and do not provide detailed requirements for individual modules (Jawitz et al., 2001). Thus, the education provider has the flexibility and freedom to assess the outcomes, which is described by Williams (2002) as a “double-bind for faculty” as there is little concrete guidance from the accrediting bodies on assessment methods or materials, yet the accrediting bodies require a legitimate assessment process.

**Assessing Engineering Outcomes**

Williams (2002) reports that ABET lists evidence which may be used to assess and demonstrate student competency for defined engineering outcomes to include, but not limited to, the following:

(i) student portfolios, including design projects, 
nationally-normed subject content examinations, 
alumni surveys that document professional accomplishments and career development activities, and 
employer surveys and placement data of graduates.

Jawitz et al. (2001) summarise the approaches adopted to change engineering programmes to an outcomes based assessment approach as the flowing:

(i) Retain existing contents but restructure documentation to an outcomes based format.
(ii) Check and adjust the course content and objectives to meet the required outcomes.
(iii) Review the entire programme to meet the outcomes based criteria and as part of on-going curriculum improvement.

Jawitz et al. (2001) note that Option (iii) is the intended goal of the ECSA accreditation process, but it is likely that Option (ii) will probably be the strategy adopted by most.
programmes, given time and workload limitations. Case & Collier-Reed (2010) show that in the Mechanical and Chemical Engineering Departments at the University of Cape Town (UCT) Option (ii) has been adopted with articulation between course level learning objectives, programme level outcomes and assessment methods.

Jawitz et al. (2001) report that the Civil Engineering Department at the University of Pretoria have adopted a standardised course template, a course articulation matrix and a curriculum articulation matrix to assess the outcomes required for ECSA accreditation. Within the course template, the learning outcomes are specified in general terms and the course articulation matrix is used to link the course outcomes to appropriate leaning activities and assessment methods. The course outcomes are then linked to the programme outcomes using the curriculum articulation matrix with course outcomes linked to the levels of the programme as introductory, intermediate or exit level. An interrogation of the curriculum matrix thus indicates the matching of the programme outcomes with the outcomes required by ECSA at the exit level. This process has resulted in a focus on assessment techniques to match the required learning outcome, with an emphasis on well defined and robust assessment of outcomes at the exit level. Using this “bottom up” approach from the existing programme and processes has resulted in staff buying into the outcomes based assessment.

A program level down approach was used the Chemical Engineering Department at UCT where staff formulated their own programme outcomes, listed which courses articulated to meet the programme outcomes and, lastly, the programme outcomes where checked against the outcomes required by ECSA. A table was used to link course outcomes with programme/ECSA outcomes (Jawitz et al., 2001). A similar approach was used at Iowa State University (ISU) in the USA where course outcomes are mapped to the 14 ISU competencies, which in turn are mapped to the 11 ABET outcomes to detect any deficiencies (Brumm et al., 2006).

A combination of a bottom up and top down approach was used in the Electrical Engineering Department at Wits in curriculum development (Jawitz et al., 2001). The weight of individual assessment components of courses to meet the ECSA outcomes were assessed and an audit of student performance of the ECSA outcomes was undertaken. The problem of a student passing a course, but failing a particular assessment component within the course which is related to meeting an ECSA outcome, was highlighted.

It was found that design and laboratory courses provide clear evidence of effective assessment, but that some of the “soft” outcomes were more difficult to assess (Jawitz et al., 2001). Case and Collier-Reed (2010) report that, for the assessment of the “Impact of Engineering Activity” outcome, the Mechanical Engineering Department at UCT has introduced into their fourth year project an ethics questionnaire to be completed prior to data collection, a risk assessment form to be completed by each student when undertaking practical activities and the students are required to write a short essay on the impact of their project on society. These components are then assessed by both internal and external examiners to assess if the student has satisfactorily met the outcome.

In order to assess the “work effectively as an individual, in teams and in multidisciplinary environments” outcome, Chemical Engineering at UCT utilise group projects undertaken in their final year design and research projects where individual and group assessments are made and oral presentations are used to assess individual competence. In Mechanical Engineering at UCT, final year design courses taken by different engineering disciplines are used to show competence to work in a multidisciplinary environment (Case & Collier-Reed, 2010).
The fourth year design project at Mechanical Engineering at UCT is used to demonstrate independent learning ability by students needing to acquire knowledge not covered in the programme while Chemical Engineering use a problem based learning approach in a final year course with limited lecturer input. The assessment of problem based learning is done in regular examinations and reflective student journals (Case & Collier-Reed, 2010).

At Mechanical and Chemical Engineering at UCT, supervisors are required to report both on the professional and ethical conduct by a student and on the students’ ability to exercise judgement and to limit their responsibility to within their competence (Case & Collier-Reed, 2010).

Assessment of Student Competency to Meet Engineering Outcomes

Williams (2002) reports that, as a consequence of ABET’s recommendations, portfolios have received a “prodigious share of attention” as a means of assessing outcomes by engineering faculty staff, but note that the use of portfolios to document student learning can lead to difficulties. These include increased workloads by faculty staff and students not appreciating the link between course goals and portfolio objectives. As a consequence, Williams (2002) suggest the development of a portfolio that meets the needs of engineering education and suggests five principles to be incorporated in the portfolio:

(i) defining the outcome or learning objective,
(ii) identifying appropriate skills and mapping them to courses in the curriculum where they should be developed,
(iii) correlating course objectives to portfolio objectives,
(iv) facilitating opportunities for students to reflect on their own learning, and
(v) assessing student learning for the benefit of both students and staff.

Williams (2002) concludes that more research is needed to demonstrate the use of portfolios over other data collection/assessment methods and believes that the successful use of portfolios will require a change in culture within engineering education.

Direct evidence of the required student competencies are determined at Iowa State University (ISU) from student portfolios, employer evaluations of both students internships and graduates five years after graduation, and the results of the Fundamental of Engineering examinations (Brumm et al., 2006). Indirect evidence such as graduate surveys, examiner evaluations and placement statistics, complement the direct measures. Using the direct measures, a numerical rating and hence ranking for the different competencies is obtained. The above measures can be used to give a general assessment of graduate competencies, but may not be able to measure the competencies of individual students.

The engineering disciplines in the Faculty of Engineering at the University of KwaZulu-Natal (UKZN) have discipline specific methods of assessing the competency of students to meet the outcomes required by ECSA. With the exception of Agricultural Engineering, the disciplines have created a matrix of links between assessment of module outcomes and the outcomes required by ECSA outcomes, with the final year design project and dissertation modules forming the bulk of these links in most disciplines. One potential problem with this approach is that a student may pass a module, but fail a component of the module where the ECSA outcome is assessed. This has resulted in some modules having sub-minimum criteria set to ensure that the student has to pass both the module and the ECSA outcome in order to proceed. The Agricultural Engineering discipline at UKZN has successfully adopted an
individual student portfolio approach to ensure that each graduating student is competent to meet the ECSA outcomes at the exit level. Further details for this approach are given below.

Use of Portfolios to Assess Outcomes

Williams (2002) include a definition of a portfolio as follows:

“A portfolio is a purposeful collection of student work that exhibits to the student (and/or others) the student's efforts, progress, or achievement in given areas. This collection must include: student participation in selection of portfolio content; the criteria for selection; the criteria for judging merit; and evidence of student self-reflection.”

Portfolios are a broad assessment tool for assessing both student learning and technical expertise and for the demonstration of these competencies. Portfolios can be generally categorised as formative or summative (Brumm et al., 2006). Formative portfolios focus on learning and provide feedback to students while summative portfolios focus on learning outcomes and demonstration of the required competency. The use of portfolios can promote learning and provide outcomes assessment data without over burdening staff or students (Heinricher et al., 2002).

Brumm et al. (2006) report that portfolios are increasingly moving online with the advantage of efficient and effective assessment, use of intelligent database controls, electronic guides and graphical design templates and list a number of institutions where competency based ePortfolios have been successfully implemented. The benefits of electronic portfolios include increased student awareness of their learning processes, promotion of consistent teaching skills across the faculty and the facilitation of goal setting and archiving and sharing evidence (McNair et al., 2006). The use of digital portfolios to streamline assessment is necessary to get staff to utilise ePortfolios in their courses (McNair et al., 2006). Knott et al. (2005) caution against the use of paper portfolios over multiple semesters as students lose evidence and rarely refer to evidence once it is submitted, whereas ePortfolios allow students to archive evidence and to easily access it when required.

At ISU the students can upload artefacts that demonstrate their competency (e.g. reports, examinations, videos, design projects) to their ePortfolio and are not restricted to evidence from academic settings. Students are required to explain the significance and impact of the evidence and self assess and rate the evidence against key actions associated with the competency (Brumm et al., 2006). For assessment, the evidence in the student’s ePortfolio can be viewed by competency theme and commercial online software is used for assessment, development, coaching and learning. With the use of electronic portfolios, the faculty workload at ISU was expected to be reasonable with each academic staff member required to assess approximately four ePortfolios per year.

ECSA Portfolio for Agricultural Engineering Students at UKZN

In response to the requirement by ECSA that all engineering graduates must be competent to meet the ECSA outcomes at the exit level, the Agricultural Engineering discipline at UKZN introduced an ECSA portfolio for all students in the discipline in 2007. The portfolio is developed over the four years of study and students are required to:

(i) Understanding of the competencies and skills associated with each of the ten ECSA outcomes by:

Critical evaluation of his/her progress in terms of ECSA outcomes (by, inter alia, cross-referencing to undergraduate module outcomes). Identification of examples of skills and competencies associated with each of the ten ECSA outcomes is required.
Understand and appreciate the assessment criteria associated with each of the ten ECSA outcomes by:

Critical evaluation of his/her performance in terms of the ECSA assessment criteria (by, inter alia, cross referencing assessment criteria as stated on undergraduate module templates).

Understanding of the standard of competencies required at the introductory, intermediate, and exit level by:

Critical evaluation of outcomes and assessment criteria (as stated on module templates) by, inter-alia, cross-reference to Bloom’s taxonomy, for courses completed during his/her academic career.

Understanding of the importance of attaining each of the ten ECSA outcomes by:

Citing examples of where competencies have been demonstrated by the student.

Demonstrate the ability to construct a professional portfolio, showing competence to meet all ECSA outcomes. The portfolio must adhere to the appropriate structure and literary style, be professionally presented, and provide both a summary and detailed evidence of the development of the competence and competence at the exit level to meet all ECSA outcomes.

An electronic template is provided to students which contains sections for all ten ECSA outcomes with assessment criteria, which were extracted largely from the ECSA documentation (ECSA, 2008). Each criterion includes sub-sections for “Introduced”, “Further Developed” and “Exit Level” for the student to summarise evidence of their developing competency to meet the assessment criteria. An extract from the ECSA Portfolio Template is shown in Figure 1. Although evidence of the development of the competence is not an ECSA requirement, student awareness of the need to develop competence in the outcomes, and the links between module outcomes and ECSA outcomes, are important in the education process.

The ECSA portfolio is a duly performed (DP) requirement for the Agricultural Engineering programme and students cannot graduate until their ECSA portfolio is completed. Students are required to submit the electronic template, without detailed appendices, at the beginning of their 2nd, 3rd and 4th years of study, completing as much as possible of the template. Academic staff annually review the submissions and add comments to the template before returning these to the student for updating and submission in the following year. As students are expected to work on their portfolios over the end of year vacation, the vacation work requirement for the programme has been reduced by two weeks.

With the introduction of the ECSA portfolio in 2007, final year students in 2007 were required to show their competence in the ECSA outcomes at the exit level only and the full portfolio was phased in with final year students since 2009 having been involved in the development of their ECSA portfolios since their 2nd year of study. The ECSA accreditation team in 2008 found that the use of the portfolio contained satisfactory evidence that individual students were competent in the outcomes required by ECSA.

A matrix is also provided as a guide to the students showing the link between module outcomes and ECSA outcomes for different levels, as shown in Table 1. Students can thus use evidence of developing competency and meeting the outcomes at the exit level from any appropriate module. A printed version of the complete portfolio is submitted at the end of their 4th year which includes the summary of evidence as shown in the template in Figure 1 as well as detailed cross referenced appendices with the required evidence collated over the four years of study. The final portfolio is then examined by both internal and external examiners and the examiners are required to specify what remedial action is required from the student if competency at an outcome is assessed to be inadequate.
The use of the portfolio approach to outcome assessment means that students are not restricted to a component of assessment in a particular module, but are able to select the best evidence to use to demonstrate their competency and are able to provide more than one source of evidence if necessary. Students are encouraged to interact with all module lecturers to understand the potential link between the module outcomes and the ECSA outcomes, and are thus aware of the competencies required by ECSA of all engineering graduates. The students are also required to reflect on the level of competencies attained in the modules they have completed.

### OUTCOME 1: PROBLEM SOLVING

<table>
<thead>
<tr>
<th>Learning outcome:</th>
<th>Demonstrate competence to identify, assess, formulate and solve convergent and divergent engineering problems creatively and innovatively</th>
</tr>
</thead>
<tbody>
<tr>
<td>Assessment Criteria:</td>
<td>Application of a systematic approach to problem solving</td>
</tr>
<tr>
<td>Gives example(s) of where you have defined a problem and identified criteria for an acceptable solution</td>
<td>Y/N</td>
</tr>
<tr>
<td>Introduced</td>
<td>Click here to enter text.</td>
</tr>
<tr>
<td>Further Developed</td>
<td>Click here to enter text.</td>
</tr>
<tr>
<td>Exit Level</td>
<td>Click here to enter text.</td>
</tr>
<tr>
<td>For the same problem identified in (1.1), gives example(s) of how you identified and acquired the necessary information and/or engineering and other knowledge and skills</td>
<td>Introduced</td>
</tr>
<tr>
<td>Further Developed</td>
<td>Click here to enter text.</td>
</tr>
<tr>
<td>Exit Level</td>
<td>Click here to enter text.</td>
</tr>
</tbody>
</table>

Examiners comments and recommended remedial actions if any competence not demonstrated for Outcome 1

<table>
<thead>
<tr>
<th>Competence Demonstrated</th>
</tr>
</thead>
<tbody>
<tr>
<td>Y</td>
</tr>
</tbody>
</table>

**Figure 1.** Extract from the ECSA Portfolio Template

The annual feedback to students from academic staff on the submitted interim portfolios should enable the student to learn what is required in the portfolio and that subsequent submissions should improve. With approximately 60 students between 2nd and 4th year, the load on the five academic staff reviewing the interim submissions is fairly heavy. In addition, the assessment of the printed final copy of the portfolio is also time consuming, and the time required from the use of a single external examiner from industry is difficult to obtain. The
time required by both staff and students when portfolios are used to assess competence in outcomes was identified by Heinricher et al. (2002) as major weakness.

**Table 1.** Extract from the ECSA Outcomes Assessment Matrix for the Agricultural Engineering Programme at UKZN

[1 = introduced (formative), 2 = developed (formative), 3 = concluded (summative)]

<table>
<thead>
<tr>
<th>Year</th>
<th>Module</th>
<th>ECSA Outcome</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>01</td>
</tr>
<tr>
<td>1</td>
<td>ENME1DR P1 Engineering Drawing</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>ENAG1EN P1 Engineering</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>MATH132 P1 Applied Mathematics 1A (Eng)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>CHEM163 P1 Chemistry &amp; Society</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>MATH131 P1 Mathematics 1A (Eng)</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>PHYS110 P1 Mechanics, Optics and Thermal Physics</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>ENAG1DE P2 Engineering Design</td>
<td>1,2</td>
</tr>
<tr>
<td></td>
<td>ENAG1MT P2 Introduction to Engineering Materials</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>CHEM173 P2 Chemistry &amp; Society</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>MATH142 P2 Applied Mathematics 1B (Eng)</td>
<td>1,2</td>
</tr>
<tr>
<td></td>
<td>MATH141 P2 Mathematics 1B (Eng)</td>
<td>1,2</td>
</tr>
<tr>
<td></td>
<td>PHYS120 P2 Electromagnetism, Waves &amp; Modern Physics</td>
<td>1,2</td>
</tr>
<tr>
<td></td>
<td>ENCV1EP H2 Engineering Practice</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>ENAG4BD PY Design Project</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>CTEC733 P1 Business Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ENAG4HY P1 Environmental Hydrology</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>ENAG4BM P1 Bioproduction Systems &amp; Management</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>ENAG4SW P2 Soil &amp; Water Conservation Eng</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>ENAG4EC P1 Environmental Control</td>
<td>1,2</td>
</tr>
<tr>
<td></td>
<td>ENAG4EH P2 Engineering Hydrology</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>ENAG4EA P1 Electrical Applications</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AGPS305 P1 Field Crop Management</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td>AGPS307 P1 Orchard Management</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ENAG4WS P1 Workshop Course</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ENAG4VW Vacation Work</td>
<td></td>
</tr>
<tr>
<td></td>
<td>AGEC240 Farm Financial Management</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>ENAG4SW Soil &amp; Water Conservation Eng</td>
<td></td>
</tr>
</tbody>
</table>

It has been noted that the flexibility given to students to utilise evidence from different sources frequently results in different sources of evidence being used to show competence for the different criteria for a given outcome but which are not related, for example, to show a systematic approach to design as the evidence provided for the different criteria are not linked to the same design problem. It was also evident that some of the criteria used in the template were not understood by some students, and hence the wording has been simplified and changed to encourage students to use evidence from the same example(s) when showing competence to meet the specified criteria for a given outcome.

Another current problem with the ECSA portfolio is the current inability in the university system to ensure that students complete and submit their annual interim assessments. This is increasingly becoming a problem with some students not updating and submitting their
portfolios every year. As a consequence, approximately 50% of the final portfolios submitted are found to not contain sufficient/adequate evidence at the exit level for one or more outcomes. These results are similar to results reported by Heinricher et al. (2002) who conducted a trial of students paid to develop a portfolio to assess ABET outcomes and found that, although the students found the compilation of a portfolio beneficial, less than 50% of the students completed and submitted a physical portfolio.

Once the remedial actions specified by the examiners have been completed by the student, the outstanding components of the portfolio have to be re-assessed by the examiners which, in turn, places additional burden on the examiners.

**Discussion and Conclusions**

From the literature reviewed, accrediting bodies of engineering programmes at universities generally require an assessment of student competence in specified outcomes. The best methods used to perform these assessments is still widely debated but the use of portfolios, particularly digital portfolios, is being increasingly used. Other methods used internationally, but not adopted in South Africa to date, include standardised examinations, alumni surveys that document professional accomplishments and career development activities, employer surveys and placement data of graduates, although these methods cannot be used to determine the competencies of individual graduates.

The use of an ECSA portfolio by the Agricultural Engineering discipline at UKZN to ensure that all graduates are competent at the exit level to meet the ECSA outcomes has been in use for more than four years. Some of the advantages of the portfolio approach is the flexibility it gives students to demonstrate their competence, the student awareness of the links between module outcomes and the ECSA outcomes, the reflection on what has been learnt and how competencies have been developed from different modules and the discipline to compile a professional portfolio over a four year period.

Some of the disadvantages of the portfolio approach is the heavy work load on staff doing both the interim and final assessments, the additional work load on students to submit updated interim reports annually, and the current lack of enforcement on the submission of the annual interim reports by students.

One solution to improve the use of the ECSA portfolio is the use of a digitally archived portfolio with associated tools to ease assessment and thus reduce staff work loads. A definitive assessment of an engineering programme to meet the ECSA outcomes is the use of employer surveys of recently employed graduates and it is suggested this approach should be investigated for use in South Africa. This would provide clear evidence of the graduates competence to meet the demands of the workplace, but it is conceded that not all graduates will be included in the survey and any deficiencies noted could only be used to subsequently improve the academic programme and thus only benefit future graduates.

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ECSA. (2004). Whole Qualification Standard for Bachelor of Science in Engineering (BSc(Eng))/Bachelors of Engineering (BEng): NQF Level 7 Document : PE-61/E-02-PE. ECSA, Johannesburg, South Africa.


Language Provision in First Year Engineering Education in South Africa: A Reflective Overview

Dawn Snell¹ and Laurie Woollacott²
School of Chemical and Metallurgical Engineering, University of the Witwatersrand, South Africa
¹dawn.snell@wits.ac.za, ²lorenzo.woollacott@wits.ac.za

Abstract

Language-focused educational measures are an important component of engineering degree programs. They are needed to satisfy outcome requirements with regard to professional communication skills, the attainment of mastery in academic literacies, and, for some students, the advancement of their proficiency in the language of instruction. However, the issues related to the provision of such measures are complex and do not fall within the domain of the expertise of most engineering educators. This paper presents a reflective overview of these issues with the intention of making the complexities accessible and digestible to engineering academics interested in the subject.

Setting The Scene

“In South Africa, teachers on access programmes immediately describe their students as having ‘language problems’, but diagnosing the problem, or more difficult still, assisting to solve the problem eludes most.” (Rollnick, 2010a, p 153)

Many questions arose when we set about re-evaluating our provision of language-related educational measures in the first year programme in the School of Chemical and Metallurgical Engineering at Wits. Why do we do what we do? What alternative measures are there and how effective are they? What are their conceptual underpinnings? To what extent are they informed by research or an understanding of how language influences learning?

The more we read and reflected on such questions, the more we realized just how complex the issues actually are. A suspicion arose and gained increasing conviction that the momentum of existing practice in our own and possibly in other institutions of engineering education in the country may be masking the complexities involved and that important issues and insights were possibly being overlooked or ignored. Accordingly, we compiled from our reading and reflection this overview of what seemed to us to be the issues that were most relevant to the provision of language focused measures in engineering education in South Africa. We share it for any who, like us, would appreciate a primer on the subject that is accessible and digestible, and covers the main issues without getting lost in the detail or in the theory.

The overview is structured in five parts. Part I provides a theoretical background and looks beyond language as a vehicle for communication to consider the intimate relationship between language and learning. Part II looks at the language landscape in the country with a view to gaining a deeper appreciation of the nature of the language proficiencies of our entrants. Part III draws from Parts I and II to discuss the rationale for the provision of language-focused measures in the context of engineering education in South Africa. Part IV classifies the options for such provision based on a broad review of language measures that
have been implemented in practice. The paper concludes in Part V with a discussion and a number of recommendations.

I: Language and Learning

Language, written or oral, is more than just the medium by means of which communication amongst learners, instructors and professionals takes place. It is also the medium of the mind.

“Language is the link between student and teacher.” (Rollnick, 2000, p95)

We begin this overview by outlining and discussing very briefly the ways in which language influences learning. To begin here is important for several reasons. Firstly, it will look at a number of theoretical positions that underpin arguments made at various points in the paper. Secondly, it will map out the scope for the provision of language-focused measures: it will highlight where and how language influences a student’s academic performance, experience, and education and, therefore, what it is that language-focused measures may need to target.

Language and the mind

That language is a dominant medium for human communication is obvious. However, as the header to this section puts it, it is also the medium of the mind. Many philosophers and psychologists conclude that it is a primary medium for thinking and for cognitive development – especially higher order cognitive development – and it is also an important medium by means of which instructors mediate that development. For example, Luria (1959) argues that language enables you to interpret your environment and make useful generalizations: it enables you to label the relevant parts of your world which in turn enables you to regulate and organize it. Saljo (1999, p81) puts it this way: “Concepts are the sources through which human beings render intelligible events that are open to many different interpretations”. Searle traces cognitive abilities back to the way the mind has been constituted through language (see, for example, the overview in Broekmann & Pendlebury, 2002). Vygotsky (1978) famously has placed language at the centre of his psychology of learning, social reproduction and the development of higher order cognitive functioning.

The implication of these observations is that the focus of language-related measures should be broader than an interest just on measures for developing professional communication skills.

Mediation and learning as construction of knowledge

Too many teachers in higher education still think of education in terms of the transfer of knowledge. Constructivist theorists reject this notion and instead argue that a person’s knowledge and understanding is self-constructed as they engage with information, contexts and learning tasks. As Vygotsky states, “academic concepts are not assimilated and learned ... and are not taken up by memory, but arise and are formed with the help of the most extreme tension in the activity of [one’s] own thinking” (van der Veer & Valsiner, 1994, p365).

Vygotsky argued that this learning-by-self-construction can be advanced through ‘mediation’. The process involves the mediator (teacher or more-competent-other) interacting with the learner to understand where the learner is with regard to what is being learned and then interacting further to nudge the learners’ self-construction of knowledge towards more advanced understanding (Daniels, 2001). Vygotsky argued further that mediation is particularly important for advancing academic concepts which are different from and
sometimes counter intuitive to ‘everyday concepts’. He introduced the concept of a ‘zone of proximal development’ (ZPD) as the extent of learning currently attainable by a learner – the current potential for advancement of understanding given the current state of a learner’s conceptual development. Knowledge about the nature and extent of learning a student can currently attain constrains and guides how a mediator interacts with a learner. It also implies that there is a limit to the extent of student learning that any educational session, module or class should attempt to facilitate. Students are unlikely to learn anything meaningful if the intended extent of learning is greater than the associated ZPD: rather they are likely to ‘get lost’, stressed, or even alienated (Mann, 2001).

This perspective on the dynamics necessary for effective student learning highlights the central importance of language: it is what connects teacher and learner (Rollnick, 2000). Proficiency in the language of instruction is essential if these teacher-learner interactions are to be effective for learning.

**Language, discourse and literacy**

When we talk about, for example, ‘the language of engineering’ we actually mean ‘the discourse of engineering’ and are referring to more than grammar and syntax. We are referring to the specific vocabulary and language peculiar to a particular engineering practice (Lave & Wenger, 1991). It is this discourse – this language – that enables clarity of conceptualization, thinking and communication in that practice. Without command of that discourse a person cannot gain meaningful access to that practice.

Literacy means, in the first instance, proficiency in reading and writing and the decoding and making sense of symbolic language. However, it can also look beyond everyday language usage and can refer to proficiency in a discourse. For example, Cummins (1981) distinguishes between literacy related to everyday discourse and literacy related to academic discourse: “Basic Interpersonal Communication Skills” (BICS) and “Competent Academic Language Proficiency” (CALP). In similar vein, Paxton (2007) talks about a progression from oral discourse acquired at home (primary discourse) to the development of symbolic and textual literacy learned at school (school literacies) to the development of more advanced literacies (academic literacies) learned at college and university.

Paxton’s progression is helpful for illustrating why academic literacies are crucial to student success and learning at university. Firstly, the progression highlights the way in which academic discourses are qualitatively different and more complex than school and home discourses. For example, the kinds of language used at home, in written work at school and in argument at university are different. Also, the range of language usage expands from speaking/listening to include reading/writing to include more advanced academic activity. Secondly, Paxton’s progression points to increased demands being placed on language: the volume, complexity, and degree of sophistication and abstraction of concepts and mental activities are all much greater at university than at school. For example, consider the list of practices associated with academic literacy which Rollnick (2010a), citing Parkinson (2000), gives.

“reading scientific texts; note-taking; integrating information from several sources; distinguishing important from incidental information; presenting information orally and graphically; translating experience ... into written form; ... organising information into a coherent form; ... planning own writing; ... drawing links between concepts … and the observed world; ... explaining anomalous findings.” (p164)

The increased demands on language mean that a higher level of language mastery is needed: for example, to participate meaningfully in seminars, tutorials, debate and the like and to
interact effectively with peers, teachers and advanced texts requires more refined and sophisticated language than is generally needed at school. Another example of the more sophisticated use of language is the contrast Rollnick (2010a) makes with regard to language use in writing: “knowledge telling vs knowledge transforming, …arranging ideas vs creation of an argument, … an instrumental view of writing vs a process constitutive of knowledge itself” (p 166). Without the requisite mastery of language a student will be constrained in his/her ability to cope with the complexities and learning demands of a tertiary environment and, importantly, the extent and effectiveness of his/her learning will be constrained. For example, several researchers (Boughey, 2002; Gee, 1996; Paxton, 2007) report situations in which students struggling with a new discourse tend to revert to familiar discourses that are not appropriate. Sibomana (2010 citing Paxton 2007 (p45) and Gee 1996) puts it this way:-

“Students make meaning by reworking past discourses, appropriating and adapting new discourses to make them their own’ … but when [they] have not mastered the secondary discourse … they may fall back on their primary discourse or they can use another related secondary discourse” (p30).

Situated learning, mastering discourse and developing literacy

Sfard (1998) contrasts learning by ‘acquisition’ with learning through ‘participation in practice’ – ‘learning by osmosis’ or ‘just picking it up’. To participate in practice involves, among other things, working with ideas and processes in context (Lave & Wenger, 1991). Learning happens as the ideas and processes are ‘labelled’ and meaning is assigned to those labels and as the relevance of the ideas and processes are recognized and meaningful connections are made. Developing the conceptual frameworks and the associated labelling systems – the discourse or language – happen together in an intimately integrated manner. Unless learning is ‘situated’ or ‘embedded’ in this way the deep connection between labels and their meaning in that practice can’t be made.

These observations have a number of implications. First, they emphasize the importance of effective feedback, mediation and reflection: clearly these can facilitate and augment the processes of meaning-making and connection-making just described. Second, if students do not develop literacy at the discourse level they can’t master the practice – they might be able to use the words but not with understanding. Third, language-focused educational measures should be *embedded* in and *integrated* with disciplinary content (Amos & Fisher, 1998a, 1998b; Wertsch, 2000).

Summary: the significance of language mastery

Lea and Street (1998) refer to academic literacy as “mastery over a secondary discourse” (cited in Rollnick 2010, p 156) pointing out that mastery over the language of instruction must be sufficiently advanced that it enables free and effective engagement with the subtleties and fine distinctions associated with tertiary level academic discourse and the wide range of language usages which that involves.

II: The Language Landscape

Entrants to higher education in South Africa present a bewildering array of language attributes and competencies. This presents a challenge for understanding the needs which language-focused measures must address. In this section, we address this issue by reviewing the nature of the language proficiencies of university entrants in the country and the factors affecting them.
The role of English

There is a growing debate both internationally and here that the mode of instruction in higher education should be more multilingual in multilingual countries such as ours. In the light of this debate, our emphasis on English needs to be explained. Firstly, English is the global language of communication for engineering and engineers anywhere who are not conversant in the language are at a disadvantage. Secondly and consequently, English is the dominant language of engineering texts. Thirdly, the earlier discussion about the role of language in learning and in discourse, point to the importance of having instruction in a language that has a strong, extant discourse in modern engineering. In South Africa, this means either English or Afrikaans.

A diverse multilingual landscape

Table 2 gives information on the distribution of ethnicity and first language use in the country. Most South Africans speak more than one language. Urban drift and the ethnic interactions common to Township life complicate the picture further. For example, it is not uncommon for a student to speak two languages at home, to go to a township school where a third language is dominant among several that are spoken and to take a fourth language, English. It is claimed, but without research verification, that there are 6 million English first-language speakers in the country and 18 million English second-language speakers (da Silva, 2008).

Table 2: Distribution of Ethnicity and Language Usage in South Africa

(This data, taken from the 2003 Census, is the most up to date information currently available.)

<table>
<thead>
<tr>
<th>Ethnic Distribution</th>
<th>Most Spoken Languages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Black</td>
<td>isiZulu 24%</td>
</tr>
<tr>
<td>White</td>
<td>isiXhosa 18%</td>
</tr>
<tr>
<td>Asian</td>
<td>Afrikaans 13%</td>
</tr>
<tr>
<td>Mixed ethnicity</td>
<td>9%</td>
</tr>
<tr>
<td>Total for these 3 languages</td>
<td>55%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Other Languages Spoken</th>
<th>Other Languages Spoken</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sepedi 9%</td>
<td>SiSwati 2.7%</td>
</tr>
<tr>
<td>Setswana 8.3%</td>
<td>Tshivenda 2.3%</td>
</tr>
<tr>
<td>English 8.2%</td>
<td>isiNdebele 1.6%</td>
</tr>
<tr>
<td>Sesotho 7.9%</td>
<td>Other 0.5%</td>
</tr>
<tr>
<td>Xitsonga 4.4%</td>
<td>Total for these 8 languages 44%</td>
</tr>
</tbody>
</table>

Factors affecting English proficiency in South Africa

With regard to levels of English proficiency among South African university entrants, at least four influences interweave to produce a complex picture. The first has already been described – the diversity of the multilingual landscape complicated further by differences in cultural and religious backgrounds. The other three influences – the English curriculum structure, the mode of instruction at school, and the quality of schooling – are discussed next.

Influence of the English Curriculum structure: Three levels of English are offered for instruction purposes at school: English-1 is intended for English mother tongue speakers; English-2 is intended for students who are not English mother tongue speakers though they may be multilingual; and English as subject intended for students not wishing to take English as a language intensive course. Each offering develops the language to a different level of
proficiency. Prior to 2009, English-2 was offered at both higher and standard grade. Gibbon et al (2006) have reported that, compared to higher grade English, standard grade English failed to develop adequate proficiency in critical thinking – a competency critically important at university.

Influence of current modes of instruction at school: The official position with regard to mode of instruction is that the first three years of schooling are conducted in a mother tongue after which English (Afrikaans in some cases) is the official mode of instruction. This is a ‘transfer model’ in that, for most students, there is a transfer – a sudden switch – from mother tongue instruction to instruction in a second language. Many voices claim that this model can impair the development of the second language (Alidou et al., 2006; Heugh, 2005, 2009). A recent study argues as follows.

“One cannot expect a child to begin learning a new language as subject and also to use this as a medium of instruction at the same time. If one tries to hurry the process, the child will neither learn the new language well enough nor the other important subjects. We now know that most children who have to try to learn about mathematics and science through a language they do not know will not succeed.” (Alidou et al., 2006)

If this argument is valid, it may constitute a systemic cause of low levels of proficiency in English in many university entrants that can be traced back to primary school.

Simelane et al (Simelane, 2007; Woollacott et al., 2011) and Rollnick (2010a) all report that the de facto mode of instruction can be very different from official policy: it can be mother tongue instruction or English with code-switching to a mother tongue when the teacher wishes to clarify explanations. These alternate practices may be the result of teachers compensating for the inadequacies of the transfer model. Whatever the case may be, the result of the practices seems to be not only that proficiency in English is not adequately developed in many English second language learners but also that students tend to develop a dependence on mother tongue explanations in a way that impedes their progress when they get to university (Simelane, 2007; Woollacott et al., 2011).

Influence of the quality of schooling and English teaching: Zerbian (2010) asserts that the quality of schooling has a profound effect on the English proficiency of English 2nd language speakers in the country. In this regard, the legacy of apartheid education exerts an ongoing influence. For example, Jansen (2011) describes the education system as ‘sinking deeper into mediocrity’ while Bloch (2009) refers to it as a ‘toxic mix’. The quality of resourcing and teaching is variable and tends to improve from rural to township to suburban and to private schools. In many cases, the English proficiency of the teachers themselves is an additional factor affecting the quality of English teaching (ibid. Simpkins, 2005). Interestingly, it seems that the English grades of school leavers do not correlate well with their actual levels of proficiency (Woollacott et al., 2011).

Overall Impact on English proficiency: The different dimensions of diversity that have been mentioned combine to bring about considerable variability in the English proficiency of students entering university in the country. The extent of this is hard to gauge and is the subject of ongoing research (Cliff & Hanslo, 2009; Scott et al., 2007; Simpkins, 2005).

Implications for the provision of language measures in higher education

To conclude this section we make the following observations.

1) Proficiency in English is a priority in engineering education.

2) The majority of university entrants to South African institutions of engineering education are English 2nd language speakers. In many cases, their mastery of English
needs to be improved if it is not to compromise their ability to engage effectively with tertiary education conducted in English. A similar argument pertains for entrants to institutions where Afrikaans is the medium of instruction.

III. Rationale Behind The Provision Of Language Measures

Three imperatives drive the provision of language measures in engineering education.

1) The need to develop professional communication skills: Globally, engineering graduates are required to possess these skills. There is broad agreement about what these are as may be seen from various taxonomies of engineering competencies and from lists of required outcomes published by accreditation bodies (Woollacott, 2009).

2) The need for students to become proficient in the relevant academic literacies: Our review of language and learning demonstrated that the progression from school to university was accompanied by a transition into more advanced academic discourses and that these were associated with language proficiencies that were more complex and sophisticated than at school. Therefore, all entrants, irrespective of their proficiency in the language of instruction, must negotiate this transition. However, this can be more complex and difficult for students whose first language is not the same as the language of instruction of the institution they enter.

3) The need some students have to master English as the language of instruction: This follows directly from the previous point. If English is to be the language of instruction in engineering education, for which a very strong argument can be made, and given the diversity of English proficiency among South African university entrants, provision should be made for those students who have English as a 2nd language to ensure that their level of English proficiency is sufficiently advanced that it does not constrain their ability to engage freely and effectively with the tertiary-level academic tasks. A similar argument can be made when Afrikaans is the medium of instruction.

IV: Categories of Language Measures

No single theory, model or body of research is, on its own, complex enough to provide a satisfactory basis for successful language provision practice. (Paraphrase of Collins et.al., 1999, p 21, cited in Rollnick 2010)

Innumerable language-focused educational measures are reported in the literature and several reviews of such measures have been published (see, for example, Boylan & Bonham, 2007; Pinto, 2001; Rollnick, 2010b). From our reading and our own experience, we identified a number of broad distinctions among these measures that suggested a way of classifying them into five qualitatively different categories. We present these in this section in the belief that the categories constitute a convenient conceptual framework distilled from practice that is useful for thinking about the kinds of approaches that have been adopted and what can be done to address language-related issues.

Category 1: Extra-Curricula Language Support Measures

The exemplar for this category is the writing centre. This is a centralized facility to which students go on a voluntary basis to seek assistance from expert language tutors. The approach is ‘writing intensive’ in that the primary mode of support is intensive individual engagement with the student with respect to drafting, correcting, re-drafting and getting feedback on pieces of written work. Writing can focus on course assignments or fluency in writing, or it can be more personally oriented such as the development of self-expression and
linguistic skills. The writing centre approach is highly regarded to the extent that it has gained the status of a global movement for over 25 years (Griswold, 2003).

**Category 2: Language Development and Remediation Measures**

The focus here is technical proficiency in the language of instruction: precision of interpretation of text and spoken language and precision and fluency of expression. Typically, a stand-alone course or module is provided by language experts as a service module for the engineering programme. Extensive practice in the language is given through assignments and corrective feedback in order to nudge the students towards greater language proficiency and improved levels of written fluency and correctness.

The measures are usually deployed to assist students whose proficiency in the language of instruction is not at a level considered necessary for them to be able to cope with the academic demands they will encounter at university. We recognize two subcategories of measures – remedial and developmental. What differentiates the two is the perceived reason for the low level of language proficiency of the students.

*Subcategory 2A: Remedial or ‘language repair’ measures* are based on a deficit view of the students’ language proficiency: their language is seen as being deficient in some way and so measures are needed to ‘fix up’ or repair the perceived deficiencies.

*Subcategory 2B: Developmental measures* are based on a view that the student’s prior language development has been ‘delayed’ in some way and so measures are required to accelerate that development to the levels needed.

There is a growing consensus, supported by evaluation data, that, in general, neither approach is very effective in achieving substantial improvements in the language proficiency of the students (Calcagno & Long, 2008; Rollnick, 2010a). Part of the reason seems to be that the labels ‘deficiency’ or ‘delayed development’ are a misdiagnosis. Severe inadequacies in the schooling system would seem to be a more appropriate diagnosis given the earlier discussion on factors affecting English proficiency in the country. A further reason seems to be that, as a result of the misdiagnosis, the measures implemented focus too much on the technical aspects of language proficiency and far too little on the mastery of discourse. Some support for this conclusion comes from the comparatively better results achieved by measures in the next category which do focus on discourse.

**Category 3: Academic Literacy Measures**

The distinguishing characteristic of measures in this category is contextualization in discourse. The development of technical proficiency in language is seen as only one aspect of the larger goal of developing proficiency in tertiary-level academic discourse – developing skills in areas such as higher-order thinking, formulation of argument, debate, and academic writing. The earlier discussion on language, discourse and literacy provides a background for understanding the rationale behind such an approach. The general structure of measures in this category is a stand-alone module provided as a service course in the main disciplinary programme. We recognize two sub-categories, one focused on academic discourse and the other on both academic and engineering discourses.

*Sub-category 3A: The generic academic literacy approach.* The rationale here is to have students work intensively with language in the context of developing their proficiency in academic discourse. Two examples from our institution will illustrate the approach. The School of Electrical Engineering commissioned the development of a ‘critical thinking’ course which has students engage critically with issues ranging from ethics and science
fiction to poetry and Shakespeare. In similar vein, our school commissioned a course on the social history of technology. Both are reading intensive (students must read a range of texts critically) as well as writing intensive (students must submit assignments and receive extensive feedback on the quality of their argument and of their language usage). Granville and Dison (2005; 2009) have shown that the effectiveness of measures such as these can be enhanced if the feedback given students is intensive, if appropriate dialogue is encouraged and if students are required to engage in reflective activities.

Sub-category 3B: The contextualized academic literacy approach. The structure and philosophy of the approach here is identical to the previous one. The only substantial differences are that the focus is on disciplinary discourse as well as academic discourse, and the course and its content are designed, and sometimes delivered, in conjunction with disciplinary experts. The ‘Commanding English Model’ reported by Christensen et al (2005 cited in Rollnick 2010) is a good example of this approach. Evaluations have shown that it can improve students’ overall grades by one letter grade. Other examples of this kind of contextualization have also been reported (Artemeva et al., 1999; Kotecha et al., 1990; Rollnick, 2010a; Skinner & Mort, 2009)

Category 4: Engineering Skills Measures

The focus in this category is professional communication skills and other generic engineering skills such as technical drawing, teamwork, and principles of design and problem-solving (Ford & Riley, 2003; Ford & Teare, 2006). Typically, a stand-alone course is offered, usually in the first year programme, to develop competencies in these aspects of engineering. In addition, such courses are run by engineering academics sometimes with help from literacy experts. This means that the language-focused aspects of the course are, or can be, highly contextualized – more so than in the previous category. However, the language-focused aspects of communication skills courses tend to be rather narrowly focused on the technical precision of language usage and the methods used to develop such precision tend to be similar to those used in developmental or remedial measures.

Category 5: Embedded Language Measures

The characteristic feature of this category is that the language-related measures are fully contextualized in disciplinary discourse by being located in the disciplinary courses themselves (Airey & Linder, 2009; Messer, 2005; Rutar & Mason, 2005; Smith et al., 2004). Jacobs has conducted some interesting research in South Africa on how this approach can be implemented in engineering education among other disciplinary areas (Jacobs, 2005a, 2005b, 2007a, 2007b).

Embedded measures can be run by engineering staff possibly with help from literacy experts. In this respect, embedded measures are similar to engineering skills measures (category 4). However, where engineering skills focus on technical language proficiency, embedded measures pay attention to the full range of academic literacies. For example, our introduction to engineering course uses opportunities afforded by the engineering content to give attention to matters such as the nature of knowledge, note taking skills, learning by making summaries, reflection, and group work skills. Students are required to critically read texts on these issues, to apply what they learn to the learning of the relevant engineering content, and to write reflective assignments on their findings.

We recognize the following sub-categories of embedded measures.
Category 5A – Single course embedded approaches: The illustration just given serves as an example of the embedding of literacy-focused measures in a single engineering course.

Category 5B – Integrated approaches: Here the embedding of language-focused measures is applied in more than one course and, ideally, across the curriculum (Ford & Riley, 2003; Jacobs, 2007b; Smith et al., 2004). Apart from the benefits of multiple reinforcements, this approach has the added advantage of exposing students to the ‘voices’ of multiple discourses with a consequent enriching of their overall development (Christensen et al., 2005).

Discussion

The above categories have been presented in a way that illustrates several progressions that we consider pertinent when distinguishing between different language measures. These are as follows:-

a) A shift in perception from language as an instrument of communication to language as discourse to language as a medium of thinking and learning.

b) A shift in focus from technical language proficiency to academic literacy to mastery of disciplinary discourse.

c) A progression from stand alone measures to measures that are more embedded and contextualised in disciplinary content.

d) An increase in the degree of involvement of engineering staff in the measures provided.

With regard to the relative merit of different approaches for provision of language-focused measures, hard evaluation data is limited and only general indications can be given. The consensus is that measures focused only on developing technical language proficiency are ineffective and that it is best to contextualize language-focused measures in relevant discourses and, in particular, to foster mastery of academic literacies (see, for example Rollnick, 2010a). There is solid theoretical support for this consensus as explained in Part I of the paper.

Common to many language measures across all categories are a number of pedagogies that seem to be have particular merit. Writing intensive measures stand out and appear to have a double benefit – both as a language measure and as a means of enhancing learning. Rollnick (2010a, p166) explained this as the result of the “close and dialectical relationship between the ability to write and the comprehension of the material which is being written about”. There are also positive indications about the efficacy of intensive feedback and a focus on reflection (Granville & Dison, 2005, 2009).

V. Conclusions

The stated purpose of this paper was twofold: to provide a coherent overview of the major issues associated with the provision of language focused measures for students entering engineering education in South Africa and to orientate such an overview to the ear of engineering educators not particularly versed in the practice. To do this we reviewed theory relating to the relationship between language, discourse and learning, and reviewed the diversity of language proficiency, particularly English proficiency, among entrants to engineering education in the country. These reviews provided the basis for establishing a three-point rationale for the provision of language-focused educational measures in the engineering programme: to develop professional communication skills, academic literacies and mastery of the language of instruction. We then reviewed the range of language
measures which have been implemented in practice as a means of gaining insights into different ways in which language-focused educational measures can be provided. We now draw from those insights to make some concluding remarks about the provision of language measures for our context of engineering education in South Africa. We direct these remarks to the educator who was hired for his/her expertise in engineering and not for their expertise in language.

The advancement of language proficiency means more than an improvement in the technical precision of language usage, or a means for addressing a primary cause of student attrition or the development of required professional communication skills. It means developing the ability of students to function freely and effectively in an environment where they are called to make sense of advanced concepts and language and to use non-everyday, advanced discourses in an environment that places before them tasks that are intellectually demanding, varied in nature, and extensive in volume. We have tried to show that to achieve such advancement will go a long way to addressing the other issues cited.

The kinds of measure that can be used to advance language proficiency turn out to be within the reach of engineering educators to implement themselves. Language experts can be useful resources in various capacities such as in language support capacities such as writing centres. However, we would argue that engineering educators can and need to be the prime movers in advancing the language proficiency and discourse mastery of their students. Our reasoning is quite simple. The most effective way to advance the kind of language proficiency we have just described seems to be to engage students intensively in the language of relevant discourses. It seems to us that a good way to do this is to recognize those aspects of existing courses which afford opportunities to have students engage with the engineering material in ways that are language intensive in nature. Resources would be needed to do this but we suspect that the effectiveness of deploying resources in this way would far exceed the rather limited effectiveness of deploying them as has been done in the past. We would argue further that there is a double and synergistic benefit to implementing discourse-focused language measures in this way. Advancement in language proficiency is one; enhancement of learning is the other.

References


The Impact of an Alternative Approach to Teaching in Thermodynamics II using Spreadsheets: A Case Study

Graham Thurbon
Department of Mechanical Engineering, Durban University of Technology, South Africa.
grahamt@dut.ac.za

Abstract
To investigate how delivery affects student understanding an alternative method of teaching and learning was undertaken in the introductory subject Thermodynamics II at the Durban University of Technology (DUT). Conducted as a multi paradigm study considering both quantitative and qualitative data, it was undertaken as a single case study. Run over half a semester, lectures were halved and the remaining periods used as combined interactive computer sessions and tutorial time. Using a constructivist approach to learning, students were required to generate spreadsheet solutions for two assignments associated with the laws and processes of Thermodynamics. A multiple response questionnaire concept test designed using a spreadsheet was undertaken by students during the intervention. It related to information from class theory and the spreadsheet assignments and automatically marked the answers, providing immediate feedback to students. As in previous semesters the remainder of the semester was lectured in the usual manner by a colleague.

To investigate how students learn Thermodynamics and what problems they have and why several students were individually interviewed towards the end of the semester using a semi-structured approach. Further a student study habit survey was undertaken, mostly using Likert scales and was analysed with SPSS using a cross-tabs approach.

The written class tests, one in each term as normally undertaken in a semester, were used as a performance indicator. As a control group, the previous semester test and examination scores were compared with those of the intervention semester.

Whilst the intervention did not improve pass rates some interesting findings did appear. Study time was seen as a significant factor for success. Further, students need to be encouraged to make more use of computers during their studies to improve their computer skills, spreadsheets being one area where this can be done.

Introduction
South African Education
The face of the South African education system has changed to an outcomes based education (OBE) system regulated by the National Qualification Framework (NQF) with quality control administered by the Higher Education Quality Committee (HEQC), under the terms of the Higher Education Act of 1997. The new Funding Framework Policy (Ministry of Education, 2004) to one considering throughput rates has also had an impact on Institution funding. Increased access to tertiary education has also changed the demographics of the student population to be more representative of the population as a whole, thus redressing past discriminating practices of the apartheid era.

Whilst this has been welcomed by many it has also brought with it new problems such as students who are underprepared for tertiary education (Badat, 2010, p.9). Much blame for this
has been attributed to the school education system (Cosser & Letsaka, c. 2009, p.5). Many institutions have attempted to redress this problem by introducing various measures such as intervention programmes (Alexander et al., 2005), bridging, foundation and extended programmes.

Along with the new education system have come new ways and ideas to approach teaching and learning, with much research being undertaken in this area, and new ways of approaching this have been investigated and implemented. Traditional methods of teaching such as lectures are however still the predominant method of knowledge transfer used in tertiary institutions. However, they are often “inappropriately applied” (Ramsden, 2003, p.147), considered as “old fashioned” by some and “inappropriate in the modern learning environment” (Cox, 1994, pp.58-59) and often considered of little teaching/learning value (Ehrlich, 2002, p.24; Felder & Brent, 1996, p.44). In the new OBE system, assessment is guided by the Criteria and Guidelines for the Assessment of NQF Registered Unit Standards and Qualifications (South African Qualifications Authority, 2001), with the recommendation that multiple assessment methods be used together with a variety of assessment instruments.

**Thermodynamics**

Sprackling (1993, p.viii) writes of thermodynamics:

> Thermodynamics is one of the major subjects of classical phenomenological physics, a subject of great power and beauty. Nevertheless, it is, for many students, a difficult subject and one that they do not understand on a first (and often, only) reading. To them the subject seems to be a collection of subtle concepts, linked by countless equations with no underlying framework.

Scott and O’Connell (2000, p.1) suggest that learning thermodynamics is very abstract, especially the fundamentals, typically requiring “students to have moved from concrete to abstract thinking”. First time learners of thermodynamics often find it very conceptual initially, an area that Heywood (2000, p.201) indicates, presents students in higher education with difficulty. Although the language and nomenclature is fairly universal in thermodynamics, two important terms that have often been inappropriately used or described are heat (Jong et al., 2002, p.2; Loverude et al., 2002, p.147) and work (Jong et al., 2002, p.3).

**Theoretical Rationale**

There has been much research and study about teaching and learning over the last few decades. New insight and media available has opened alternative avenues to teachers and learners alike, one of them being computers.

**Teaching and Learning**

Ramsden (2003, p.6) suggests “that we can improve our teaching by studying our students’ learning”. South African Qualifications Authority (2000, p.25) intimates that learning takes place on a continuum and is an ongoing process that never stops. In many Higher Education Institutions, although the norm is the formal lecture in which students are often “passive recipients” (Ramsden, 2003, p.108), learning can also take place when students interact with each other in group situations. Marton and Säljö’s work of defining students’ approaches to learning as surface or deep (Atherton, 2005a, para.1; Case & Marshall, 2004, p.606; Ramsden, 1992, p.46) has widely influenced how we consider learning. Further, learning styles and inventories have been proposed and developed. The four modalities of the VARK model (Fleming & Baume, 2006, p.2) were considered in their simplest form in this study, as
used in the study habit survey discussed later. Learning cycles have also been developed and the Kolb cycle (as cited in Atherton, 2005c) influenced the planning of this study.

Whatever learning takes place one crucial factor that needs to accompany it is motivation. Practising appropriate assessment and feedback methods can be an important motivating factor, but equally as powerful a de-motivator if not handled tactfully (Rowntree, 1987, pp.200-201). Atherton (2005a, para4) suggests that deep and surface learning “correlate fairly closely with motivation: “deep” with intrinsic motivation and “surface” with extrinsic”. Race (1999, p.3) warns teachers not to “mistake lack of confidence for lack of motivation”.

Students can be motivated by the way in which things are taught. Active participation can be used to aid learning, students often being more motivated by doing rather than simply listening. Atherton (2005b, para.1) describes constructivism as the educational approach that “emphasises the role of the learner in constructing his own view or model of the material”. Inherent in the constructivist philosophy is the idea of reflection (Murphy, 1997b, para.10), also seen in the Kolb learning cycle. In this study students were responsible for their own learning and pace of progress. They interacted with their group members and computers, engaging in multiples activities using high order thinking.

Group work has several advantages. It encourages participation from the group members whereby they can actively share ideas (Race, 1999, p.4), debate issues and hopefully come to a common conclusion or compromise. Group work involves listening to group members, discussing ideas, illustrating solutions, a form of “peer tutoring (Bruffee, 1995)” (as cited in Heywood, 2000, p.209), requiring activities associated with the Cognitive domain of Bloom’s Taxonomy (1956) (as cited in Atherton, 2010). It is therefore a more student-centred style of learning with the teacher becoming a facilitator, guiding students when and where necessary. Heywood (2000, p.210) warns however that the choice of groups needs to be considered, as random selection “can lead to conflict and a failure to learn”. Besides teamwork they would need to actively carry out the tasks on the computer, utilising their keyboard skills, involving activities in the Psycho-Motor domain (Dave (1975), as cited in Atherton, 2010). Further, Heywood (2000, p.232) suggests that computers may aid in the development of three dimensional capabilities of students. In this case students represented a two dimensional pressure versus volume (p-V) graph of a three dimensional situation, the volume swept out by a piston in a cylinder.

Bourne et al. (1995, p.239) envisage that engineering education will become “electronically-based”, with students being able to learn anywhere at any time. Whilst computers are used fairly widely in education today, with their added visual component, Scott and O’Connell (1999, p.2) state that, in relation to thermodynamics, “there are only a few computer-oriented materials and no experiments”, with only some thermodynamic “learning aids”, but typically “textbook or computer descriptions”. In recent years this has changed with an ever more widening amount of thermodynamics related web sites opening up to assist in teaching and learning. Ramsden (1992, p.160), however, warns about the use of computers becoming “an electronic page-turner that rewards surface approaches to learning”. Further Race (1999, p.64) warns us that students can “become sidetracked by all sorts of fascinating (or inappropriate!) things”.

**Spreadsheets in teaching**

In this study the emphasis was on self-paced offline learning using spreadsheets, utilising a constructivist approach. Rothermel et al., (2000, p.230) describes spreadsheets as providing a “declarative approach to programming, characterized by a dependence-driven, direct-
manipulation working model”. Quick to learn, they are mostly menu driven and have the added advantage of quickly being able to represent processes graphically, updating themselves as the problems change. However, Brown and Gould (1987, p.259) estimate that between 20% to 40% of spreadsheets contain user-generated errors. Rajalingham (as cited in Oke, 2004, p.894) “argues that the problem of spreadsheet errors has adverse real-life consequences on engineering education”. Bissell (as cited in Oke, 2004, p.897) however points out that errors in graph plotting are reduced when compared to hand drawn methods.

The paradigms

In this study both quantitative and qualitative data were collected. As such a multi paradigm study was undertaken, operating both in the Positivist and the Interpretivist paradigms. Neuman (2000, p.65), in reference to positivism, points out that “most people never hear of alternative approaches” and since much of engineering and engineering education operates within a Positivist paradigm it was familiar to me already. However part of the study and data analysis was outside of this realm, falling within the interpretive social science family, as described by Neuman (2000, p.70).

The interventions

There were four main interventions included in this study. The first three were completed during the first term of the semester, the intervention period, and the last one was conducted at the end of the semester. The second term was run as a typical semester would do, with a colleague taking over as he normally did. Table 1 below shows the breakdown of a typical semester compared to the intervention semester.

Table 1. Comparison of a typical semester compared with the intervention semester.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Typical semester</th>
<th>Intervention semester</th>
</tr>
</thead>
<tbody>
<tr>
<td>Classroom lectures/week</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>Tutorials/week</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Computer laboratories/week</td>
<td>0</td>
<td>2</td>
</tr>
</tbody>
</table>

Note: Tutorial and Computer laboratories combined as a triple period

Each intervention is described below.

The computer spreadsheet exercises – the class was divided into groups of three students and they operated autonomously to generate two spreadsheets, the first considering the main processes of thermodynamics in a cycle involving three consecutive processes. The students were to make a spreadsheet showing the cycle on a pressure-volume (p-V) diagram and work out the net work done for the cycle. The second spreadsheet was to be able to solve the non-flow and steady-flow energy equation for any one unknown variable. These were run in the computer laboratories in parallel with class theory. Each group was assigned a group code for each exercise to use as a file name to ensure anonymity when assessing another group’s file. At the end of each exercise each group was assigned another group’s file to peer assess by solving an unseen problem, all guided by a rubric. Some of the files were later assessed by me and an assistant to moderate the marks allocated by the students.

A study habit survey – a two page questionnaire mostly answered using Likert scales. It was divided into six main sections, these being: personal information, information exchange, library use, subject specifics, practical experience/exposure and study techniques. The first considered Senior Certificate symbols, ethnicity, parents qualification, repeating and subject
goal. The second considered availability and use of electronic media and the third what use was made of the library services. The fourth considered what resources students had, time and type of activity spent on studying tasks. The fifth was related to any sort of exposure to work or engineering since school and the last related to study techniques (learning style (VARK), group or individual study, note taking and tutorials).

A concept test – this was a quick multiple response test used to test the students knowledge gained doing the spreadsheet assignments together with the class theory covered during that time. It was designed on a spreadsheet and required the student to choose the correct answer(s) to statements posed in association with a graphic connected with each series of questions. There were five pages, the first considering processes, the second cycles, the third a closed system and the fourth an open system. They entered their student number at the start and resaved the read only file with their student number as the file name at the end. A fifth page gave them an overall percentage scored for the test and further broke the analysis down into a percentage score for each page. Thus students got immediate feedback of their performance, something that Ramsden (1992, p.99) suggests is one of the most important components of assessment.

Interviews – one-on-one interviews using a semi-structured approach (Denscombe, 2003, p.167; Esterberg, 2002, p.87; Gillham, 2000, p.65) were conducted with nine students towards the end of the semester. Initially chosen using purposive sampling (Fink & Kosecoff, 1985, p.59) to cover as wide a scope of marks, ethnicity and gender as possible, several of those finally interviewed were chosen by accidental sampling (Fink & Kosecoff, 1985, p.59).

The mark allocation of the intervention semester compared to a typical semester is broken down in Table 2 below. Each spreadsheet assignment was only allocated 5% and was incorporated in the test 1 mark. No attempt was made to do any analysis on the laboratory practical component other than in statements made during the interviews.

Table 2. Breakdown of all mark allocations given to the various assessments.

<table>
<thead>
<tr>
<th>Assessment</th>
<th>Intervention semester (%)</th>
<th>Typical semester (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spreadsheet exercise 1 (incorporated in Test 1 mark)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Spreadsheet exercise 2 (incorporated in Test 1 mark)</td>
<td>5</td>
<td>0</td>
</tr>
<tr>
<td>Study habit survey</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Concept test</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Interviews</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Test 1</td>
<td>40</td>
<td>30</td>
</tr>
<tr>
<td>Test 2</td>
<td>30</td>
<td>40</td>
</tr>
<tr>
<td>Practical</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>SEMESTER MARK</td>
<td>100X0,4 = 40</td>
<td>100X0,4 = 40</td>
</tr>
<tr>
<td>EXAM MARK</td>
<td>100X0,6 = 60</td>
<td>100X0,6 = 60</td>
</tr>
<tr>
<td>FINAL MARK</td>
<td>100 (=40+60)</td>
<td>100 (=40+60)</td>
</tr>
</tbody>
</table>
The Data and Analysis

The data consisted of both quantitative and qualitative data and was analysed accordingly. Each intervention will be discussed below.

The two spreadsheet assignments were marked using peer assessment at the end of each exercise. An unseen problem for the spreadsheet to solve was attached to a guiding rubric, with Likert scales from 1(strongly disagree) to 5(strongly agree) to assess for the given criteria as laid out in the subject’s learning outcomes. Since it was their first time at assessing, a sample of each assessment was also marked by the researcher and an assistant to generate a moderation weighting factor to account for too lenient or stiff a mark by the students. This was 0,9664 for the first assignment and 0,8882 for the second. In addition, if the student peer mark and assessor mark deviated by more than 25%, then the final student mark became the average of the two marks, thus still keeping the peer assessors mark in the loop. One of the problems found during the analysis of the first assignment on processes and cycles was that the graphs were typically not dynamic such that they automatically updated themselves when new data was entered, leaving original practice graphs in the spreadsheet or else each graph point had to be worked out first then manually entered into the spreadsheet. Another problem observed was that although three processes were often evident on the graph they often did not close the loop (i.e. complete the cycle), some processes either all starting at the same point, as seen in Figure 1 below, or the third process going off in the wrong direction. One student interviewed described the graphs as “where you can actually do tuts practically, practically so that you can see how the process operates”, showing that they were gaining an understanding of how the processes work whilst doing the assignments. Concerning peer assessment students reported that they found it “easier the second time round”, when they assessed assignment 2, indicating that they were becoming more proficient at it.

The study habit survey, with mostly Likert scale answers, was analysed in SPSS using a cross tabs approach by comparing the students final semester mark with each of the forty two components in the six main categories mentioned previously to see if any of them were a predictor of success, i.e. a pass. Only one variable showed significance, with a 2-sided Pearson Chi-Square of 0,027, and that was own ‘time spent doing thermodynamics per week’. Students who spent three or more hours per week, as suggested in their learner guide (Thurbon, 2006, p.6), were twice as likely to pass as those who spent two hours or less a week. This result is shown in Figure 2 below. Other studies have shown minimum study times varying between one and a half to five hours per week, depending on the subject (Emenalo, 1989, p.18; Rau and Durand (2000), as cited in Plant et al., 2005, p.97). Plant et
al.’s (2005) study further suggests that it is not only the quantity of study time that can affect the improvement of grades, but also the quality of study (i.e. undisturbed, self-regulated and focused study).

![Time spent doing thermodynamics per week](image)

**Figure 2.** Time spent doing thermodynamics per week

When considering students preferred learning style, the majority indicated that they were visual learners, at 49%, a figure much lower than Felder and Brent (2005, p.61) at 82%. They also suggest that visual learners, who are generally predominant in undergraduate engineering classes, appear to have a higher probability of passing than other types of learners. However, the majority of teaching is done verbally using lectures, indicating a mismatch of teaching and learning styles. Since much of thermodynamics involves the use of charts, graphs, diagrams and tables in order to get results, those inclined towards visual learning would be more likely to relate to the subject and, although not a significant finding, it was interesting to note that visual learners obtained the highest pass rates in this class.

The concept test, run during a laboratory session, automatically checked the answers students gave, giving them their score immediately as described earlier. All the answers students gave were then gathered into one master spreadsheet and analysed from there. One of the most important aspects of the test was the choice of sign convention used, which students had to declare at the start of the test by indicating which one they were using since this affected the choice of answers given later. There were two to choose from, one being used by Joel (1987, pp.15,61-62) and a set of notes available in the library, the other by Eastop & McConkey (1993, p.xii), both books commonly used for this subject. There were 82 respondents, 55 of whom chose the first (since the majority had the library notes), 18 the second, 7 students tried to use both simultaneously and two students didn’t specify. Only six students got 100%, although some students were seen going back over their tests, so this number is not reliable. The scores obtained for each page using either convention were very similar as indicated in Table 3 below, indicating little difference in using the conventions.

Talking to the students later about the test was positive, as the test gave them immediate feedback as to how well they had performed. Page 1 required an understanding of the energy types (work and heat), directions and quantity calculations, and use of the first law of thermodynamics to find the change in internal energy. Results of this test showed that only 62% of students recognised the heat term correctly. Similar tests done by Meltzer (2004a, pp.1440-1441), run as both written and by interview, showed that heat was identified correctly only by 40% to 56% in written tests and only 34% in interviews. Concerning the use of the first law of thermodynamics, required to answer the third question, only between
11% and 29% correctly identified the answers from applying the first law. In a similar study, using the same process as applied in this study, Loverude et al. (2002, p.140) found that only between 20% and 25% of students recognised the relevance of the First Law of Thermodynamics, even after being prompted with it.

Table 3. Summary of concept test percentage scores per page for both sign conventions.

<table>
<thead>
<tr>
<th>Page (content)</th>
<th>Joel/notes</th>
<th>Eastop and McConkey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Page 1 (processes on p-V)</td>
<td>46</td>
<td>41</td>
</tr>
<tr>
<td>Page 2 (cycles on p-V)</td>
<td>52</td>
<td>50</td>
</tr>
<tr>
<td>Page 3 (non-flow)</td>
<td>85</td>
<td>83</td>
</tr>
<tr>
<td>Page 4 (steady flow)</td>
<td>77</td>
<td>75</td>
</tr>
<tr>
<td>Overall average</td>
<td>71</td>
<td>68</td>
</tr>
</tbody>
</table>

Page 2 tested the students’ knowledge on cycles, defined as ‘a number of processes following each other sequentially, to form a closed loop’. It also tested their graph analysis capabilities and their understanding of the first law of thermodynamics. Here only 56% chose the correct quantity of work output. Considering the quantity of heat output from the cycle between 69% and 77% chose incorrectly, a higher figure than Meltzer (2004a, p.1436) where between 40% and 60% of students gave incorrect responses. Another difficulty students have is distinguishing between work, heat and internal energy, all different forms of energy, also reported by both Meltzer (2004a) and Loverude et al. (2002).

Pages three and four showed diagrams of a closed and an open system respectively and students had to identify the different components and energies involved. Students generally did better in both of these since they involved only observation and identification rather than deductive logic required to analyse the systems, as was required for the previous two pages. However, between 3% and 8% of students chose the locations of heat and work incorrectly. This was similar to the findings of Meltzer (2004a, p.1437) and Loverude et al. (2002, p.142).

The interviews were conducted shortly before the start of the semester examinations. Although students across a wide band of marks and ethnicity were interviewed only one female accepted the invitation. Due to accidental sampling, five students were repeats, which limited the input from first time students. However, opinions about the different types of teaching approach, namely the constructivist interactive computer laboratory style adopted in the first half of the semester compared to the normal lecture approach in the second half, were obtained. Most indicated that they preferred lectures as it was more structured with specific times for tutorials although, as mentioned previously, working on the spreadsheets brought the processes to life and several said that it could be a good idea. However some students said that possibly combining learning thermodynamics and trying to generate spreadsheets at the same time was too much.

When questioned about how they liked to study, seven of the nine said they preferred to work alone although one student indicated that group work was probably a good idea since you can get opinions and help from others in the group. The other two said that they worked in study groups. When asked if they would consult a lecturer, most said that they would find help from their classmates and other students first before getting help from a lecturer. Only one
student, who had a very methodical approach to studying, indicated that he regularly consulted the lecturer. One student said that he’d rather consult friends than a tutor. When questioned further about how they learn thermodynamics, one student said that an understanding of the first section was crucial to understanding the subject as a whole, since it laid the foundation for any further work in thermodynamics. Clearly a deep learner, he questioned everything that was taught. This was in complete contrast to another student, a surface learner, who said “I would much rather learn it parrot fashion than than try and understand it, because I do not know what’s going on”, although he suggested that other people “would much rather learn the understanding of it”. Scott and O’Connell (2000, pp.1-2) indicate that to achieve in thermodynamics “requires knowing the fundamental principles and using procedures that are abstract and mathematical.” and that it often involves “strategies of learning that are more sophisticated than what is their usual previous experience of memorization and working of many example problems without generalization”.

Some of the students had been exposed to industry, either through previous work experience or in doing their work integrated learning (WIL) as part fulfilment for their diploma. This they said had helped them to gain a better understanding of the subject, since they had seen some of the equipment that was talked about in class. It can also be a motivator to better understand thermodynamics. Lack of exposure to industry can be a major drawback to understanding the subject since one cannot relate what is discussed about in class to the real world.

Other issues raised in the interviews relating to problems students have whilst studying were also raised. Some related to the subject, such as library use, practicals, computer access and past paper revision, whilst other were broader issues, such as finances and cheating, which none the less still had an impact on the success of students in their studies.

Finally, in order to get some measure of the success or otherwise of the intervention, the marks for the class tests were compared to the previous five semesters, used as a benchmark. SPSS was used to analyse all the marks appearing below. Since all the lecturing had been done by the same lecturers over that period, tests and examinations set and marked by them, there was at least consistency making the marks more valid and reliable. A summary of the test scores appears in Table 4 below.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Test 1</th>
<th>Test 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Combined</td>
<td>Intervention</td>
</tr>
<tr>
<td>Sample size</td>
<td>460</td>
<td>53</td>
</tr>
<tr>
<td>Mean</td>
<td>40,85</td>
<td>38,67</td>
</tr>
<tr>
<td>Standard deviation</td>
<td>17,79</td>
<td>15,43</td>
</tr>
</tbody>
</table>

The combined test scores histograms compared to with the intervention semester test scores for each test are shown graphically in Figures 3 to 6 below.
Figure 3. Histogram of combined previous semester test 1 scores

Figure 4. Histogram of intervention semester test 1 scores

Figure 5. Histogram of combined previous semester test 2 scores
An ANOVA test run on the previous semester and the intervention semester test scores showed that there was little difference in the test 1’s and test 2’s scores. A Paired Sample T-Test run on the intervention test 1 and 2 scores showed that there was a significant difference between them, test 2 scores being higher, as seen by the means in Table 4. This was further confirmed by a Wilcoxon Signed-Rank Test. Although neither test marks showed a significant deviation from a normal distribution, the second test did show a slight left skewness, as seen in Figure 6.

Conclusions and Recommendations

Whilst the intervention did not improve marks, as indicated by the test scores, it can be concluded that it is possible to teach in different ways and that students will respond accordingly. Although the test 1 averages were slightly lower than previous semesters, the test 2 averages were slightly higher. This means that the benefit of the intervention may only have been seen later in the semester. The problems that our students face in thermodynamics are similar to other students elsewhere, often a lack of understanding of the basics and their application, which if not sorted out early in a students learning continues to plague them throughout this and any follow on subjects. Misuse of the terminology associated with thermodynamics, specifically those of heat and work was found in both the concept test and in the written tests. A lack of understanding can also quickly lead to lack of motivation. Although most students interviewed stated a preference for lectures they did agree that the computers had some benefits in the learning of the subject, one student commenting “…but at the end of the day, we learnt something from it”.

There were many problems that occurred along the way in this study such as availability and reliability of computers and networks. Whilst the computer infrastructure is problematic at present the need for more computer related work is necessary in the programme in an increasingly technological world. A lack of the necessary computer programming skills caused further frustration for some students. There are however many more problems that our students face such as preparedness for tertiary education, lack of finances, lack of resources, safety on and off campus, theft and so on that impact on their ability to achieve their goals.
More group work is to be encouraged as it brings students together such that they can share ideas and also learn from each other. It also encourages teamwork and responsibility. Peer analysis as a teaching and learning tool needs to be utilised effectively in the programme. Another area which needs to be encouraged is reflection. Students also need to be encouraged to spend more quality study time on task to improve their chances of success.

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Constructive Alignment of Laboratory Instruction in Chemical Engineering at the Durban University of Technology

Shadana Vallabh\textsuperscript{1} and Suresh Ramsuroop\textsuperscript{2}

\textit{Department of Chemical Engineering, Durban University of Technology, South Africa.}
\textsuperscript{1}vallabhs@dut.ac.za, \textsuperscript{2}ramsuros@dut.ac.za

Abstract

Laboratory work is an integral part of an engineering curriculum. This is further emphasized in the new qualification standards for engineering programmes as a required competence, and as an important criterion in the accreditation of engineering programmes in South Africa. This suggests that a student who has completed his studies must be fully equipped with competencies associated with practical and laboratory work of the discipline. The challenge to achieving this is to firstly identify the various competencies associated with laboratory work, and ensuring that these are developed and assessed during the academic programme. In order to achieve constructive alignment in all its learning activities, the Department of Chemical Engineering undertook a review of the laboratory work associated with its learning programmes.

During the review, the key question emerged was whether the laboratory work at the Durban University of Technology (DUT) in its entirety adequately equips first, second and final year students in accordance with the objectives that should be achieved. The review has shown some weaknesses in the current laboratory learning experience. These include: students do not engage actively in this mode of instruction; they are not strongly motivated; they do not fully prepare for the lab experiment; team spirit and responsibility in group work is lacking, and there is a variance in the quality of reports submitted.

It is believed that the root cause for the above listed problems is the lack of clarity of the learning objectives and the subsequent poor design of the laboratory learning experience. During the review the following questions were answered: What are the learning objectives of a laboratory experience; are the current modes of delivery fulfilling the learning objectives; are the resources adequate to fulfil these objectives; are the assessment methods appropriate for the learning objectives; and is the type of laboratory experience appropriate to the level?

In this paper, the details of the review, the strategies implemented to address the shortcomings, and an assessment of implemented changes are presented.

Introduction

Engineering is a practice-oriented profession and since engineering practice is generally associated with making something happen in the physical world, it has been deemed essential to develop that physical world interface in the laboratory. The traditional objective of the laboratory programme is to provide a transition between the academic and the real world of chemical engineering. It is used to test and solidify the student’s understanding of a particular subject, as well as familiarize the student with various measurement techniques and tools, which will be used in his/her future engineering career. Wankat and Oreovicz (1992) reported that despite the general agreement on the role and importance of laboratory work in engineering programmes, there has been a growing tendency to reduce the amount and
significance of laboratory work since they are: expensive to establish and maintain, time-consuming in an already demanding academic programme, and may not be connected to the university’s other mission—research. To counter this tendency, laboratory work and laboratory infrastructure are now established as an important criterion in the accreditation of engineering programmes by many engineering accreditation and professional registration bodies for example: Engineering Council of South Africa (ECSA), Accreditation Board for Engineering and Technology (ABET), European Network for Accreditation of Engineering Education (ENAE), etc.

In addition to the laboratory work requirements specified in the South African engineering qualification standards, the two key desired objectives of the laboratory experience at DUT are:

- It must be an “active learning” experience which must contribute to deep learning. This instructional mode must engage the learners as active learners.
- This instructional activity must include all the domains of knowledge (cognitive, affective, and psychomotor) at a variety of levels (Blooms Taxonomy). There must be a progression in the cognitive domain from first year to final year.

Experiences at DUT have shown some weaknesses in the current laboratory learning experience. These include: students do not engage actively in this mode of instruction; they are not strongly motivated; they do not fully prepare for the lab experiment; team spirit and responsibility in group work is lacking, and there is a variance in the quality of reports submitted.

It is believed that the root cause for the above listed problems is the lack of clarity of the learning objectives and the subsequent poor design of the laboratory learning experience.

**Development of Educational Objectives of Laboratory Instruction at DUT**

To meet the above broad objectives and to fully exploit the laboratory experience as an active learning experience a review of potential competencies that can be developed and assessed in a laboratory environment was undertaken. In addition to the exit level outcomes detailed in the SA engineering qualifications standards, laboratory practices by other educational institutions and accreditation bodies were reviewed.

In their book, *Teaching Engineering*, Wankat and Oreovicz (1992) extensively critique the role of laboratory work in engineering education and present several suggestions on its implementation. They outline the various objectives that can be achieved through laboratory instruction and highlight the need for clear understanding of the learning objectives prior to design of the laboratory activity. In 2002, the Accreditation Board for Engineering and Technology (ABET) held a colloquy to further explore the issue of laboratory objectives. The primary product of the colloquy was a list of thirteen objectives that encompass the fundamental purpose of educational laboratories in engineering. The thirteen objectives detailed by Feisal et al (2005) covered diverse competencies in the following areas: instrumentation, models, experiments, data analysis, design, learning from failure, creativity, psychomotor, communication, safety, teamwork, ethics and sensory awareness. These objectives cut across many domains of knowledge i.e. cognitive domain, affective domain, and psychomotor domain, and can be grouped as:

- Cognitive domain: instrumentation, models, experiment, data analysis, and design
• Affective domain: learn from failure, creativity, safety, communication, teamwork, and ethics
• Psychomotor domain: psychomotor and sensory awareness

These objectives were successfully used by Rice University (2006) to establish the learning objectives for their laboratory programmes.

**Table 1. A Rubric to Characterise Inquiry in the Laboratory Experience. Buck et. al (2008).**

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Confirmation</th>
<th>Structured inquiry</th>
<th>Guided inquiry</th>
<th>Open inquiry</th>
<th>Authentic inquiry</th>
</tr>
</thead>
<tbody>
<tr>
<td>Problem/Question</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Not provided</td>
</tr>
<tr>
<td>Theory/Background</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Not provided</td>
</tr>
<tr>
<td>Procedures/Design</td>
<td>Provided</td>
<td>Provided</td>
<td>Provided</td>
<td>Not provided</td>
<td>Not provided</td>
</tr>
<tr>
<td>Results analysis</td>
<td>Provided</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Not provided</td>
</tr>
<tr>
<td>Results communication</td>
<td>Provided</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Not provided</td>
</tr>
<tr>
<td>Conclusions</td>
<td>Provided</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Not provided</td>
<td>Not provided</td>
</tr>
</tbody>
</table>

Whilst these fundamental objectives provided a framework for improving current laboratory practice, more specific objectives were needed to provide clear guidance in developing and implementing laboratory work at DUT. It is also important to acknowledge that laboratory instruction will be implemented differently for the different courses and at different levels in a chemical engineering curriculum. Hence, an additional frame of reference for the types of laboratory experience that a student can encounter from first to final year in the chemical engineering curriculum is useful. Domin (1999) described the essential characteristics of the types of laboratory instructional styles practiced in chemistry. This classification of the level of inquiry was further modified by Buck et. al (2008), and is presented in Table 1. This classification, which could equally apply to chemical engineering, is used to classify the chemical engineering laboratory learning experience at DUT. The laboratory work associated with the first year engineering courses in chemistry and physics are typically the “Confirmation and Structured inquiry” type experiments whilst, the laboratory work associated with the engineering courses move from the “Guided inquiry” and culminates in an “Authentic inquiry” type research project. There is a gradual progression from the practice of a focus on observing, verifying theories, a given procedure and predetermined outcomes, to putting an emphasis on thinking skills, information seeking, problem solving, multi-disciplinary, planning, communication and teamwork. The concept of a graded laboratory experience is proposed by Mathew and Ernest (2004). They proposed that the student should be progressively and purposefully made to move from a “confirmation” type laboratory experience and become fully competent to handle “authentic inquiry” type projects, during the spread of the academic programme rendering the transition smooth without educational jerks. A review of the pedagogies underpinning laboratory instruction presented by Davis (2008), considers a similar classification of the level of enquiry that is associated with the different levels of laboratory work. Davis considers some of the practical
challenges associated with the design of laboratory learning, and presents several suggestions for the design, implementation and assessment of laboratory work.

After the review of literature on laboratory instruction, the DUT framework was developed. Using the Rice University knowledge domains, the learning objectives associated with laboratory work at DUT is presented in Table 2.

Table 2. Specific learning outcomes for chemical engineering laboratory work at DUT.

<table>
<thead>
<tr>
<th>Knowledge Domains</th>
<th>Learning Outcomes (The student will be able to......)</th>
</tr>
</thead>
</table>
| Basic laboratory skills                | • Measure and record experimental variables with appropriate precision  
• Carry out laboratory procedures correctly  
• Adhere to instructions on laboratory safety and to recognise hazardous situations and act appropriately  
• Perform logical troubleshooting of laboratory procedures                                                   |
| Maturity and Responsibility            | • Effectively prepare in advance for laboratory work  
• Learn from mistakes and feedback given  
• Work effectively as part of a team                                                                                   |
| Integration and application of knowledge/experience | • Integrate and apply knowledge and experience from math, science and engineering courses to the relevant study  
• Relate laboratory work to the bigger picture, to recognise the applicability of scientific principles to real world situations  
• Explain the scientific method, including the concepts of hypothesis and experimental controls, and why objectivity is essential  
• Apply critical thinking in the laboratory  
• Recognise the relevance of data collected  
• Convert raw data to a physically meaningful form  
• Apply appropriate methods of analysis to raw data  
• Recognise whether results and conclusions "make sense"                                                                       |
| Communication                          | • Maintain a laboratory notebook with sufficient detail to permit repeatability of experiments and including additional material on the relevant experiment  
• Communicate effectively with peers and lecturer  
• Write technical reports effectively in appropriate style and depth  
• Make effective use of the library and information sources                                                                 |

The key challenge to developing outcome statements is that there must be opportunities for students to develop them and they must be measurable. Biggs (2003) who concluded that with any pedagogic approach, it is important to align learning outcomes, teaching and learning activities and assessment tasks, particularly where the intention is to encourage deep, rather than surface, approaches to learning. Biggs calls this approach “Constructive Alignment” which entails the following steps: a) Defining the learning outcomes, b) Selecting learning and teaching activities that enable the students to develop the outcomes and c) Selecting appropriate assessment activities which allows the student to demonstrate that the outcomes has been achieved to the appropriate level.
<table>
<thead>
<tr>
<th>Phase</th>
<th>Expected Performance</th>
<th>Assessment Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-prac</td>
<td>During this phase, the student is expected to:</td>
<td>The prac instructor will assess the student using an assessment rubric.</td>
</tr>
<tr>
<td>(This phase is carried out prior to the experimental work)</td>
<td>• Contextualize the relevance of the experiment.</td>
<td>Students will only be allowed to conduct experimental work if they meet the required score. Students who do not meet this requirement will have to reschedule with penalties.</td>
</tr>
<tr>
<td></td>
<td>• Identify the objectives of the experiment.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Identify the various methodologies available to address the objectives of the experiment.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Explain the underlying principles of the chosen methodology for the investigation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>During this phase, the student is expected to:</td>
<td></td>
</tr>
<tr>
<td>Prac</td>
<td>• Identify the various components (including process streams) of the equipment used</td>
<td></td>
</tr>
<tr>
<td>(This phase is carried out at the experimental bench)</td>
<td>• Identify the operational hazards and environmental considerations relevant to the investigation.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Operate the relevant experimental and related analysis equipment.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Perform all operations in a safe and responsible manner.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Gather and record process data.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>During this phase, the student is expected to:</td>
<td></td>
</tr>
<tr>
<td>Post-prac</td>
<td>• Analyze and evaluate the process data</td>
<td></td>
</tr>
<tr>
<td>(This phase is carried out after the experimental bench)</td>
<td>• Identify and present findings.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Draw conclusions and make recommendations.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Report on the experiment in the relevant format.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Report on each member’s contribution to the prac.</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 1.** Phases of chemical engineering laboratory work at DUT

With this in mind, the laboratory experience had to be structured to enable the desired outcome development and its subsequent assessment. Hence the laboratory work has been structured into 3 three phases, namely, pre-prac phase, a prac-phase, and a post-prac phase. During each phase the students are assessed against a scoring rubric which is made available to students at the beginning of each semester. The assessments have elements on cognitive, affective, and psychomotor domains. The expected learning associated with the three phases is shown in Figure 1.
The Basis or Methodology Applied

In order to constructively align the laboratory learning outcomes, teaching and learning activities and assessment activities, the Department of Chemical Engineering at DUT undertook a review of the laboratory work associated with its learning programmes. A holistic approach was used, which in the final analysis benefitted both students and staff.

Prior to the review, lecturing staff periodically visited the lab during a lab session. The purpose hereof was to evaluate the conduction of lab experiments related to their courses. With this in mind lecturing staff would be critical in commenting on the following aspects:

- Were the students able to operate the equipment and collect data with minimum assistance from the lab staff? This observation was to establish the extent to which students were adequately prepared for the lab experiment.
- Were all students actively participating in the experiment? This observation was to establish their extent of participation evidenced their depth of understanding of the lab experiment being conducted.
- Were the students constructively collaborating amongst themselves thereby creating an exchange process of sharing their skills, observations, knowledge, misunderstandings or indeed their concerns? This observation was to establish that students were indeed communicating with each other and working together to achieve the objectives of the lab experiment.

Lecturing staff would also engage with students thereby creating discussion. This enabled them to determine the extent to which students were able to correlate the theoretical knowledge and the application thereof in the lab experiments. This was further re-enforced by assessing their lab reports which would indicate students’ shortcomings or difficulties encountered in understanding the lab experiment.

In addition to the academic staff participation as set out, the role of the laboratory staff was of critical importance. During the lab sessions, laboratory staff would diligently take note of or observe the following aspects:

- Was there an understanding in students being able to differentiate the various process lines and instrumentation?
- Did students operate the equipment safely in keeping with the given guidelines?
- During the experiment were the levels of their understanding sufficiently good thereby ensuring that they were indeed noting the appropriate readings, observations, discrepancies and any other related data?
- Was there a sense of team spirit or interaction enthusiasm which gave rise to the rotating of tasks?
- Were they effectively communicating with each other and establishing a collaborative skills and information sharing process?

Having set out some of the methodology used as a final means of analysis, students were required to complete a questionnaire at the end of the lab program. The student feedback served as a valuable basis allowing for evaluation of their laboratory learning experience.

Using the learning outcomes in Table 2 as a basis, a review of the lab function and instruction was undertaken. The end result entailed feedback from lecturing staff and comments and
input from laboratory staff. This information was collectively analysed and discussed in conjunction with the student survey feedback. Having carefully established the concerns both from a student perspective and an academic/lab one, proposals were made with a view to the implementation of remedial and correctional strategies.

It should be stated that the entire exercise was a most learning one and indeed most inspirational and stimulating.

**Shortcomings of the Laboratory Functions and Instruction**

There were three major reasons for poor lab performance by students that were clearly identified: the lack of student preparation for the lab experiment, the lack of team work, and variance in the quality of lab reports.

**Inadequate Student Preparation for the Lab Experiment**

Students arrive at the lab sessions, have varying degrees of preparedness. They have neither read nor acquainted themselves with the lab manual and operating procedure therein. This is evidenced by them being unfamiliar with the equipment and instrumentation. Further they are unable to decide on what parameters to measure and on how such measurements are to be obtained with the equipment and instrumentation available.

**Lack of Knowledge in Working with Teams**

Lack of team effort in the performance of the experiment: Lab instructors reported that students were not functioning as a cohesive team during the performance of the lab experiments. There was no sharing of skills, knowledge, observations, misunderstandings or concerns. Where a student did not understand aspects of the lab experiment, the student was then merely a spectator at the lab session while other group members operated the lab equipment and recorded data. There was no sense of team spirit or interaction enthusiasm which gave rise to students rotating tasks.

Lack of team effort in writing the group report: Students do not understand the object of group participation in the writing of the report. As an indication thereof reports have been repeatedly written by a single student whereas at other times it would appear there is a total lack of motivation, inspiration or creativity in group report writing.

**Variance in the Quality of Lab Reports**

The final assessment for the lab session is based upon a written report submitted by the group. Reports are marked according to the summary, the related theory, the experimental procedure, the results and interpretation of the results. Students are given the assessment criteria used to assess the lab reports. The interpretation of the assessment criteria was not clearly interpreted or understood. This is evidenced by the varying quality of group reports submitted. Of serious concern is the lack of presentation of the relevant theory, and the poor presentation of results and the interpretation thereof. It is evidently clear that there is poor understanding and analytical abilities to integrate theory and results from the lab experiment.

**Correctional Strategies Implemented Towards Improving Lab Function and Instruction**

The aforementioned shortcomings and group performance flaws were carefully considered with a view to the implementation of various strategies to rectify the situation. The strategies were:

**Pre-lab Lecture Series:** Prior to the commencement of the lab program, a series of lectures covering lab safety, lab rules, lab assessments, working effectively in teams, and report
writing, are delivered to students. Students gained a better understanding of what was expected from them regarding lab work. This was evidenced by the greater initiative with which learners applied themselves in the lab.

**Pre-lab session:** To enable students to adequately prepare for the lab experiments, pre-lab sessions have been timetabled for students to visit the lab prior to the scheduled lab session. This affords students the opportunity to familiarize themselves with the lab equipment and instrumentation, and to determine what parameters should be measured. During the pre-lab sessions lab instructors are available for discussions should students need them. The students have come to realize the essentiality of the pre-lab session.

**Pre-lab assessment:** The conventional pre-lab quiz contained a process whereby lab instructors could at random pose questions. Students would response in their answers as they believe to be. Invariably these answers were incorrect, or an indication of total lack of knowledge or understanding of the lab experiment and equipment. With this in mind and as a basis for constructive correctional action a pre-lab assessment rubric was developed with the aim of guiding students, see Table 4 in the Appendix. The pre-lab assessment rubric was explained to the students and as to how it would reinforce and give guidance in their answering techniques. As a basis for comparison there was indeed a marked improvement in the answering performance generally for all students.

**Prac performance assessment:** In the absence of a prac performance evaluation or guideline a prac performance assessment rubric was structured, see Table 5 in the Appendix. Students are assessed on their ability to identify all process lines and instrumentation as per the given process and instrumentation diagram, explain to the lab instructor how an experimental trial will be carried out, operate the equipment as well as any related analysis equipment in a safe and responsible manner, and gather and record process data. The results were most noteworthy which again proved that with the assessment guidelines the level of understanding and commitment was comparatively by far more profound.

**Instruction on working in a team:** Prior to the lab review, students were given no instruction as to how to work in a team. It was assumed that a group of students will know how to function as a cohesive team. As part of the pre-lab lecture series, students are given instruction on how to organize themselves as a team, how to be effective when working as part of a team, and encouraged to view themselves as a learning group with the focus to help each other to learn. The results have been most encouraging. Students promote each other’s learning as they explain to each other their understanding of the equipment and its operation as well as the theory related to the experimental work. During the performance of the lab experiment, students rotate experimental tasks so that all members experience all aspects of the lab experiment.

In so far as group participation for report writing is concerned, the object of working in teams was emphasized. Students were advised of sharing knowledge, exchange of facts and group participation. This had the effect of students then appreciating that the result expected of them was to be in the form of group effort and not as individual students. To assess the effect of this remedial action, students were requested to clearly indicate what aspects of the group report they contributed to.

**Correctional Strategies Towards Improving Quality of Reports:** The report assessment criteria were revised to provide more clarity as to what is required. As part of the pre-lab lectures, the report assessment criteria are explained to the students. They were then advised
to do further reading on the theory related to the lab experiment so as to gain a better understanding of all the related parameters and their effect on each other.

Whereas a marked improvement has been noted in the presentation of data and the interpretation of results, this however has not been sufficient enough to justify student competency on the whole.

**Students Perception of their Laboratory Experience**

A student survey is conducted at the end of the lab program to assess the impact of the laboratory experience on student learning. The results of the most recent survey are shown in Figure 2. Students found lab work to be a worthwhile learning experience, their understanding of the theory was enhanced, and lab work had improved their skills and made them more aware of safety issues. Overall they felt the lab program was a success.

As regards lab objectives being discussed in lectures, notwithstanding the level of presentations from an academic perspective, students expressed concern at the lack of clarity from a holistic point of view. This point is well taken. It is constructive and conveys a concern which needs to be addressed. Coming out of this, all lab objectives, expected analyses or any end result must be well defined and explained. At the duration of this particular exercise, students should be randomly questioned thereby ensuring that they fully understand as to what is expected of them.

Average ratings were given for lab equipment always being fully functional at the scheduled time. It is indeed true to state that the functioning of lab equipment, provisioning of lab material and any other related paraphernalia is not of student concern. On the contrary the entire functioning of the lab in all respects is the responsibility of those in charge of the lab which by implication of necessity requires the lab staff and the responsible academics to ensure that this in fact is done.

![Figure 2. Student ratings of their perceptions of their lab experience in the learning categories given in Table 3.](image-url)
Table 3. The learning categories of the student survey.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Tasks undertaken in the laboratories are worthwhile learning experience.</td>
</tr>
<tr>
<td>2</td>
<td>As a result of the practicals, my understanding of the relevant theory has greatly improved.</td>
</tr>
<tr>
<td>3</td>
<td>The practical work is well integrated with the theory done in lectures.</td>
</tr>
<tr>
<td>4</td>
<td>The objectives of the practical work are adequately discussed in lectures.</td>
</tr>
<tr>
<td>5</td>
<td>The practical work has improved my skills.</td>
</tr>
<tr>
<td>6</td>
<td>The practical work has required me to do critical thinking.</td>
</tr>
<tr>
<td>7</td>
<td>The practical work has required me to do additional work after hours.</td>
</tr>
<tr>
<td>8</td>
<td>Working in groups has helped me develop my teamwork skills.</td>
</tr>
<tr>
<td>9</td>
<td>The practical work has made me more aware of safety issues.</td>
</tr>
<tr>
<td>10</td>
<td>The practical manual has sufficient detail to successfully complete the practical work.</td>
</tr>
<tr>
<td>11</td>
<td>Laboratory staff/personnel have been very helpful.</td>
</tr>
<tr>
<td>12</td>
<td>The time allocated for the experimental work is adequate.</td>
</tr>
<tr>
<td>13</td>
<td>The time allocated for the submission of the lab report is adequate.</td>
</tr>
<tr>
<td>14</td>
<td>The equipment is always available at the scheduled time.</td>
</tr>
<tr>
<td>15</td>
<td>The equipment is always fully functional for data collection.</td>
</tr>
<tr>
<td>16</td>
<td>Practical work has been marked and returned promptly.</td>
</tr>
<tr>
<td>17</td>
<td>The assessment of the practical reports is fair.</td>
</tr>
<tr>
<td>18</td>
<td>The weighting of the practical marks in the course mark is appropriate to the work done.</td>
</tr>
</tbody>
</table>

Ratings for prompt feedback on the written lab report were low. Students expect feedback in due time. The logic quite clearly would be that a prompt return of any remarks or criticism would allow them to reflect accurately on the lab report being referred to. It follows that an undue delay could put a student in a situation where he or she would lose track or not recall the aspects being brought to their attention.

Students also indicated that the time allocated for the submission of the lab report is inadequate. Having regard to this particular comment made by the students, after careful thought and within the context of that request and the academic planning, the following comments are relevant. The time limit at the present time, that is one week, is by far more than adequate. Students must develop time management skills and planning of their academic work. Similarly as they have requested prompt return of lab report criticism the prompt submission of their reports are also of import.

In concluding the effect of comments from the student provides an essential two-way communication link. The criticisms or observations submitted by them are to be viewed within a constructive spirit and accordingly allow for academic attention thereto. In the
absence of this particular communication process it is quite clear that we would be none the wiser.

**Concluding Remarks**

Students are being responsible for their lab work. They are now effectively preparing for the lab session prior to entering the lab. They are demonstrating confidence in operating lab equipment. They are enthusiastic about their lab work and look forward to operating the larger, complex pilot-scale equipment.

Students now appreciate that the results expected of them must be in the form of group effort and not on an individual basis. They are of the view that group interaction and participation has the effect of enhancing the knowledge of all group members.

**Future Improvements**

It appears that the first year students are by far more intimidated when it comes to the operating of the pilot-scale lab equipment. With this in mind, as part of the pre-lab lecture series, lab instructors must place greater emphasis when it comes to first year students in identifying process lines and instrumentation, operating units safely, differentiating measurements as well as deciding on how such measurements are to be obtained. All of this must take place with the available equipment and instrumentation.

In an effort to establish the importance of team spirit and responsibility of working in groups, students must be formally assessed in this regard after each lab experiment. So as to ensure a careful basis of performance, an assessment rubric must be designed.

Supplemental instruction on the analysis and interpretation of results should be provided. Typical experimental data should be used to illustrate how results are analysed and justified, and how appropriate conclusions are reached. Support in where students might look for information relating to the theory of the lab experiment should be provided by lecturers. The appropriate references should be included in the lab manuals.

With the proposed measures presented we are confident that there would be an all round marked improvement in student’s lab performance. The expectation is that students would conduct themselves with greater confidence, understanding and analytical abilities and consequently present lab work, report writing and general performance at a level of notable worth.

**References**


Appendix

Table 4. Pre-Lab Assessment Rubric.

<table>
<thead>
<tr>
<th>Score</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
<th>Score</th>
</tr>
</thead>
</table>
| **Brief overview of the experiment**  
(What area of chem. eng is this experiment relevant to, and what is the importance of this area?) | Students present bits of unconnected information, which have no organisation and make no sense. | The information stated is simple, but its significance is not grasped. | The information is clearly stated and significance understood. | The information is clearly stated and significance understood, and able to generalise and transfer the principles and ideas beyond the prac environment. | Score |
| **Identify the objectives of the experiment**  
(Why is this experiment being done?) | The objectives stated have no organisation and is incorrect. | The objectives stated are simple, but their significance is not grasped. | The objectives stated are clearly stated and significance understood. | The objectives stated are clearly stated and significance understood, and able to generalise and transfer the principles and ideas beyond the prac environment. | Score |
| **Identify the various methodologies available to address the objectives of the experiment.**  
(What are the various ways of achieving the objectives of the experiment?) | The methodologies stated have no organisation and is not relevant. | The methodologies stated are limited, and their significance is not grasped. | The methodologies stated are clearly stated and significance understood. | The methodologies stated are clearly stated and significance understood, and are able identify the range and limitation of application. | Score |
| **Explain the underlying principles of the chosen methodology for the investigation.**  
(How will the collected data be used to meet the experimental objectives?) | The principles stated have no organisation and make no sense. | The principles stated are simple, but their significance is not grasped. It also contains some errors. | The principles stated are clearly stated and significance understood. | The principles stated are clearly stated and significance understood, and able to generalise and transfer the principles and ideas beyond the prac environment. | Score |
<table>
<thead>
<tr>
<th>Score</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Identify the various components (including process streams) of the equipment used</strong></td>
<td>Students unable to identify components of the experimental rig correctly.</td>
<td>Students are able to identify components of the experimental rig but their significance/ function is not understood.</td>
<td>Students are able to identify components of the experimental rig. The relevance of the components are clearly stated and significance understood.</td>
<td>Students are able to identify components of the experimental rig The relevance of the components are clearly stated and significance understood, and able to generalise and transfer the principles and ideas beyond the prac environment.</td>
</tr>
<tr>
<td><strong>Identify the operational hazards and environmental considerations relevant to the investigation</strong></td>
<td>Students unable to identify operational and environmental hazards.</td>
<td>Students are able to identify some operational and environmental hazards, but the consequences are not fully understood.</td>
<td>Students are able to identify all the operational and environmental hazards, and all the consequences are fully understood.</td>
<td>Students are able to identify all the operational and environmental hazards, and all the consequences is fully understood, and also able to generalise and transfer the principles and ideas beyond the prac environment.</td>
</tr>
<tr>
<td><strong>Operate the relevant experimental and related analysis equipment</strong></td>
<td>The student has little or no idea on how to operate the equipment.</td>
<td>The student has basic idea on how to operate the equipment, but has no idea on how to change variables.</td>
<td>The student can operate the equipment, and change all the variables. The change in variables and its consequences are fully understood.</td>
<td>The student can operate the equipment, and change all the variables. The change in variables and its consequences are fully understood, and able to generalise and transfer the principles and ideas beyond the prac environment.</td>
</tr>
<tr>
<td><strong>Perform all operations in a safe and responsible manner</strong></td>
<td>Safety procedures were ignored and/or some aspect of the experiment posed a threat to the safety of the student or others.</td>
<td>Lab is carried out with some attention to relevant safety procedures, but several safety procedures need to be reviewed.</td>
<td>Lab is carried out with full attention to relevant safety procedures.</td>
<td>Lab is carried out with full attention to relevant safety procedures. The student understands the consequences of exceeding the design parameters.</td>
</tr>
<tr>
<td><strong>Gather and record process data</strong></td>
<td>Student does not know which process variables to monitor and record.</td>
<td>The process variables identified but their measurement units are not understood.</td>
<td>The process variables are identified, correctly measured and significance understood.</td>
<td>The process variables are identified, correctly measured and significance understood, and able to generalise and transfer the principles and ideas beyond the prac environment.</td>
</tr>
<tr>
<td><strong>Participation</strong></td>
<td>Participation was minimal OR student was hostile about participating.</td>
<td>Did the lab work but did not appear very interested. Focus was lost on several occasions.</td>
<td>Used time well in lab and focused attention on the experiment.</td>
<td>Used time well in lab and focused attention on the experiment, and has been proactive with all aspects of the laboratory work.</td>
</tr>
<tr>
<td><strong>Condition of the equipment and area in which the practical was conducted</strong></td>
<td>Unacceptable condition: 20% penalty from overall prac mark</td>
<td></td>
<td>Acceptable condition: no penalty</td>
<td></td>
</tr>
</tbody>
</table>
Co-Operative Learning in Thermodynamics: Solving Problems in Pairs

Willem van Niekerk¹, Elsa Mentz² and Willie Smit³
¹,³ School of Mechanical Engineering, North-West University, South Africa; ²School of Curriculum-based Studies, North-West University, South Africa
¹willem.vanniekerk@nwu.ac.za, ²elsa.mentz@nwu.ac.za, ³willie.smit@nwu.ac.za

Abstract

Mechanical Engineering students often perceive the subject Thermodynamics as difficult. To make matters worse, lecturers often have to stick to traditional lecturing methods as other methods that may alleviate the problem require substantial additional effort. In this study a first effort was made to use Pair Problem Solving (PPS), a co-operative learning strategy, to enhance the conventional teaching method used in Thermodynamics, a third year module in the Mechanical Engineering curriculum. It was hoped that for a modest effort, a significant improvement in understanding would result.

In five end-of-chapter class tests, the students were divided into groups of two and given a problem to solve as a pair, while having access to a text book and their notes. In the implementation of PPS we tried to adhere to the five principles for effective co-operative learning. The students filled in a questionnaire before and after the completion of the class tests and six students were interviewed to determine their experiences of working in pairs. We also compared the test scores with those of students taking the tests individually.

Although there were no significant improvement in the results of their semester tests, it was clear from the interviews and questionnaires that the students are very positive about PPS. They felt working in pairs helped them to understand the work better. Eighty-seven per cent indicated that they would like to work in pairs again.

We hoped that peer assessment would ensure sufficient individual accountability and positive interdependence, two of the principles for effective co-operative learning. However, this did not happen. It is possible that students were afraid of creating ill-will by giving low assessments of each other.

As this is an ongoing action research project, measures will be sought to ensure that the five principles of effective co-operative learning are adhered to as the study is continued.

Introduction

Mechanical Engineering students often perceive the subject Thermodynamics as difficult - if not almost impossible. The subject matter is at times abstract, many concepts cannot be physically demonstrated and some are not easy to grasp. In our experience, students often revert to rote learning as a strategy to pass tests and exams. They try to get hold of as many previously worked-out problems as possible in order to memorise the different types of problems and their solutions. In the end-of-term feedback, students also often complain about the lack of “worked-out problems”. This strategy seems to be quite common – also for other modules – while lecturers would probably rather see students master the fundamentals and would probably agree with Alfred North Whitehead: (1929) “The really useful training yields comprehension of a few general principles...”
The result of these and other factors is that a certain level of antagonism between the lecturer and the class can develop. I am sure most of us know what Felder and Silverman (1988:674) are talking about when they say: “Professors, confronted by low test grades, unresponsive or hostile classes, poor attendance and dropouts, know something is not working.” Johnson (1999:8) also states: “Lecturing as a singular teaching technique has repeatedly been shown to be ineffective.”

In this study, letting students solve problems in groups of two (PPS - Pair Problem Solving) was investigated as a way of enhancing the conventional teaching method used in the third year Thermodynamics module in the Mechanical Engineering curriculum. PPS is based on the principles put forward by Lochhead (1985), as well as on “pair programming” – a well-developed, successful co-operative teaching strategy used in the teaching of computer programming (Williams & Upchurch, 2001; Mentz, et al., 2008). It was hoped that for a modest effort, a significant improvement in understanding would result.

Conceptual framework

Various approaches have been proposed to replace the lecture as the dominant teaching technique. As early as 1916 John Dewey emphasized the role of social interaction as the primary source for teaching (Lutz & Huitt, 2004). Vygotsky’s social development theory also stated that social interaction plays an important role in the cognitive development of learners regarding the content as well as the nature of learning (Vygotsky, 1978). He believed that children learn through interaction with adults as well as other knowledgeable co-learners who enable them to complete tasks that they would not have been able to complete on their own. These views laid the foundation for social constructivist theory. According to this theory individuals attach meaning to knowledge through their interaction with others and their environment (Kim 2001). King (2002) supports the viewpoint that children who interact with others have the opportunity to model their problem-solving skills on each other and thereby receive feedback that leads to new comprehension, knowledge and skills. When learners need to explain their ideas to others, they are forced to reorganise their own comprehension in order to be better understood (Gillies & Ashman, 2003). New knowledge could thus be constructed through social interaction and through applying previous knowledge (Alexandrov & Ramirez-Velarde, 2006). The co-operation between learners is described by social constructivists as a process through which social interaction results in active learning (Chaparro et al., 2005). Problem-based learning, co-operative learning and collaborative learning, to name only a few, are teaching strategies based on social constructivism. All of these strategies focus on co-operation of learners which is also their central pedagogical point of departure.

Co-operative learning is a special form of group work and involves students working in teams, but meeting specific conditions (Johnson & Johnson, 2009). The benefits of co-operative learning have been well documented. Felder and Brent (2003:15) state: “A large and rapidly growing body of research confirms the effectiveness of co-operative learning in higher education.”

Current practice

It seems that traditional lecturer-based instruction is firmly entrenched in engineering education. Xiong Dan Lui (2004:31) states: “They have existed for thousands of years in China and exert an important role in teaching activities.” In Maastricht, lectures in the morning and tutorials and practical sessions in the afternoon were only replaced by a Problem-Based Learning (PBL) strategy in 1994 as a reaction to an increase in student drop-
out, a decreased intake and demands from government and industry. Since then, PBL has been implemented as a partial strategy in mechanical and biomedical engineering at the Technische Universiteit of Eindhoven. But PBL also has its limitations. The authors did a thorough analysis and concluded: “The accent (of PBL) will be more on application and integration of knowledge than on acquisition” and therefore “separate direct instruction and supervised practice are needed...” (Perrenet, et al., 2000:356).

The reasons that co-operative learning is not more widely implemented, despite its advantages, have been investigated by Ahern (2007) and can be summarised as lack of knowledge by lecturers about the technique, lack of ability in and skills for its implementation and lack of resources and support. It is clear that co-operative learning requires additional effort and time (Baker, 2010; Johnson, 1999; Ahern, 2007; Macieras, 2011).

It seems that there are more and better reasons than mere “resistance to change” for lecturers sticking to traditional lecturing methods – despite the problems associated with it. The principles of pair programming, a co-operative learning strategy used in the teaching of computer programming (Mentz, 2008), presented an attractive and viable enhancement of lecturer-based instruction used in Thermodynamics, a third year module in the Mechanical Engineering curriculum.

Co-operative learning

Co-operative learning can be defined as the use of small groups of learners who work together to maximise their own and their group members’ achievement when solving problems or completing specific tasks (Mentz & Goosen, 2009). Johnson and Johnson (2009) describe five essential principles that must be adhered to for successful co-operative learning.

Positive interdependence implies that members should understand that they cannot succeed as individuals but that their success is dependent on the success of the group. Mutuality needs to be established in terms of common goals that the group as a whole needs to achieve. These mutual goals should be strong enough to overcome competition and conflict between members of the group.

Individual accountability refers to the fact that members needs to understand that their input is important for the success of the group and also understand what their contribution should be. Each of the members of the groups needs to be individually accountable for their contribution towards the success of the group. Veenman et al. (2002) stress the importance of assessing the contribution of each individual member of the group.

Social skills refer to the application of interpersonal and small group skills in order to get to know and trust each other. Students need to communicate with each other and learn to listen and respect each other’s viewpoints and initiatives.

Face-to-face promotive interaction implies that partners provide help and assistance to each other, gain confidence in asking questions, share resources, challenge each other’s reasoning and encourage each other to succeed (Mentz & Goosen, 2009). Effective fact-to-face interaction results in mutual motivation and the creation of trust in each other’s opinions and actions.

Group processing means that after completion of the task, the group should reflect on how well they performed as group, what they could improve on in future and what worked well. According to Willis (2007) group work helps members of a group to clarify their ideas
through discussion, debate and by challenging each other’s ideas and opinions. It fosters a deeper understanding of new concepts and ideas after having had the opportunities to talk and explain concepts to the other members of the group.

**Pair programming**

Pair programming, in which two programmers work side by side at the same computer, execute the programming task together and collaborate on the same design, algorithm and code (Williams & Kessler, 2003), draws on the principles of co-operative learning (Mentz, 2011) as well as on the principles of peer problem solving as introduced by Lochhead (1985). Whimbey and Lochhead (1980) stated that the only way to reduce the difficulty of a problem is to have people think aloud while they solve the problem. While they vocalize their thoughts, it is possible to view, observe and communicate on the steps that they take and their activities. With pair programming, the two roles allocated to the pair are that of driver (typing the code) and the navigator (directing the problem-solving process). If the pair knows that their work will be assessed and that each of them has a specific role to perform to achieve their goals, it fosters positive interdependence between the members of the pair (Mentz & Goosen, 2009). Pair programming proves to be beneficial to students learning programming skills. Other advantages include improving student performance in programming (Nagappan, 2003), resulting in higher quality programs (Jensen, 2005), fostering greater understanding of the programming process (Howard, 2006), resulting in more focused, motivated students (Jensen, 2005) and leading to improved comprehension and learning (Williams & Kessler, 2003).

We decided to use a similar approach in Thermodynamics.

**Design and methodology**

**Research design**

As the aim of this research was to address an actual problem in an educational setting with a view to improving students’ learning and our professional performance, we decided to use practical action research (Creswell, 2008) as design. This article reports on the first phase of this action research process.

**Method**

We applied quantitative as well as qualitative research methods in order to obtain a clear picture of the focus of our research.

**Population**

The study was performed using 120 Thermodynamics third-year Engineering students enrolled for the Baccalaureus in Engineering as the population. We randomly selected 60 students to complete class tests in pairs (PPS group). The other 60 students completed the class tests individually as usual (control group). Students remained in the same group (PPS or control) throughout the semester.

**Measuring instruments**

Apart from using the marks from the class and semester tests of the two groups in our analysis, we also asked the students from the PPS group to complete a semi-structured questionnaire on their perception of group work before and again at the end of the cooperation period to determine their perceptions and experiences of working in pairs. Semi-structured interviews were also conducted after completion of the module with 6 students who worked in pairs (representing the whole spectrum of the student body) - to strengthen
our data and to determine their experiences of working in pairs. Even though we were satisfied after four interviews that we had reached data saturation (Merriam, 1998), we completed all six interviews.

**Statistical techniques and data analysis**

For the quantitative analysis, we compared class and semester test scores of the two groups with each other using an independent t-test and effect sizes to determine if statistical and practical significant differences exist between the two groups. The questionnaires were analysed by determining frequencies and percentages on the responses of students and comparing their responses before starting to work in pairs with their responses after completion of their work in pairs.

For the qualitative analysis, the interviews were transcribed and data was analysed using ATLAS.ti computer software. We used open coding as a data-driven approach (Gibbs, 2010) to determine students’ experiences of working in pairs. Themes and sub-themes were identified from the analysis of the data which will be used in our discussion of the results. The data from the interviews were analysed by one of the authors and verified and cross-checked by the two co-authors.

**Implementation**

Our goal was to implement cooperative learning without changing the normal structure of the course too much. In this way we could easily have a control group of students and a test group. The control group would experience the course in a very similar way to how students had in previous years; the test group would do cooperative learning.

**Solving problems in pairs**

Students were briefed as to what co-operative learning entails and special emphasis was placed on social skills and the way in which they needed to collaborate. All students were informed about the research and although they all had to take the tests, their further participation was voluntary. Students were assured that tests scores would be adjusted if there were a significant difference in the class tests scores of the two groups.

We opted to use cooperative learning only during class tests. A class test was written whenever a study unit had been completed. Each class tests consists of one or two problems relating to work from the study unit. All the students (in both groups) were allowed to use textbooks and notes during class tests.

Students of the PPS group were randomly divided into groups of two before each class test. The division was only shown to the students at the start of each test, so students did not know beforehand who their partner would be. The two students in a group had to work together to solve the problem and they had to hand in a single solution.

Each student in a group was assigned a specific role. The *driver* handled the pen, drew figures, did the calculations and wrote down the solution. The *navigator* presented a strategy to solve the problem, used the textbook, looked up data in tables, referred to class notes, asked questions and checked that the driver did the calculations correctly.

Every student had to assess their own and their partners’ preparation for, participation in and contribution during the test and submit the assessment online within two days after the test. The results of each student’s evaluation were made available to his/her partner.
We mentioned in the Literature Overview the five principles of effective co-operative learning. Here follows a brief overview of the actions we took in order to adhere to the five principles.

Positive interdependence is addressed by allocating a specific role which each group member has to perform during the test in order to ensure one member is dependent on the contribution of the other.

Students write the semester tests and the exam individually. Their final mark for the subject depends largely on their individual effort; this ensures individual accountability. The results of the peer assessments were also to be used to ensure individual accountability. The idea was to use the average rating obtained by a student for all assessments to weight the final mark allocated for class tests.

The students were randomly divided into groups; they could not choose their partners and had to work with students they would not normally choose to work with. This addressed the aspect of social skills.

Students interacted face-to-face as they sat next to each other during the test. A facilitator could prompt a group to have better interaction if it was necessary. The fact that they knew their work would be assessed motivated them to provide help and assistance to each other.

Group processing was realised asking each member to assess their own preparation, participation and contribution as well as that of their partner and making this assessment available to the other partner of the pair.

Assessments

The performance of the students during the course was assessed using four components: class tests (open book), semester tests (closed book), practical work and a final exam (closed book). Table 1 gives a summary of the respective weights.

<table>
<thead>
<tr>
<th>Component</th>
<th>Number of assessments</th>
<th>% of final mark</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class tests*</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td>Semester tests</td>
<td>3</td>
<td>24</td>
</tr>
<tr>
<td>Practicals</td>
<td>2</td>
<td>8</td>
</tr>
<tr>
<td>Exam</td>
<td>1</td>
<td>60</td>
</tr>
</tbody>
</table>

* The only difference between the test PPS and the control group is that the test group wrote the class tests in groups of two.

Results and discussion

The questionnaires, interviews and test scores will be discussed separately. Finally the extent to which we were able to adhere to the five principles of co-operative learning will be evaluated.

Questionnaires

An important result is that the attitude of the students towards group work changed significantly. This is clear from comparing the questionnaires that the students completed before starting to work in pairs with the answers filled in after completion of five class tests. Before starting the module, 61% of the students indicated that they like to work in groups.
After the tests 82% of the students indicated that they like to work in groups. The most common reason they gave was that it helped them understand and solve difficult problems. Also, at the beginning of the course 40% of the students indicated that the success of group work depends on the participation and input of your partner and 52% mentioned that it is easy for one student to get credit for something that he/she did not achieve. At the end of the module a few students still indicated that the success depends on the way in which the partners were prepared, but only 9% expressed concern that some students might achieve a test score that they did not deserve. Initially, students also mentioned the fact that conflict may occur when working together. After completion of the five class tests, nobody mentioned any conflict as a result of working in pairs.

An important indicator of the success of PPS is that a large majority of students (80%) felt that they gained insight and knowledge from working in pairs and 87% of them indicated that they would prefer working in pairs in future as well.

The most common concern about working in pairs was the negative effect it could have on the motivation of students to prepare for tests. In the post-test questionnaire 36% of the students admitted that they did not prepare enough for one, two or three of the five tests. They also believed that 76% of the time their partners were not well-prepared for one, two or three of the five tests. This correlates well with the fact that 35% of students working in pairs admitted that they would have prepared better if they knew they had to write the tests individually.

**Interviews**

Three main themes became clear from the interviews:

- The advantages of working in a pair
- The disadvantages of working in a pair
- The role of preparation before working in a pair

**Advantages of working in a pair**

Five sub-themes emerged from the interviews:

- Assistance; positive attitude; improvement of test scores; increased comprehension; exposure to different ways of problems solving.

Students indicated that they learnt from each other while working in a pair - “Also if I know something that he doesn’t, I will show him and then we will work together and find a good solution at the end of the day.” All but one student of the six interviewed, had a positive experience from PPS and valued the experience that they gained from working together - “I was very glad when I heard that we can work together. I think it was a very good thing.” One of the students still preferred not to work in a randomly selected pair. From the interviews it was also clear that students thought they benefited from working in pairs as their test scores were higher when working together - “If I had to work alone, my test scores would be lower.” The fact that all the students interviewed indicated that they had learnt a lot and understood difficult concepts much better through working together, is also an indication that working in a pair could be advantageous to students in Thermodynamics – “My experience is that it really helped me.... in the sense that I understood the work better. I understand the work better and when I explain to someone, that is when I really get the method, because I think I understand it and then he questions me about it and wants me to reason on what I am saying.” Furthermore, the collaboration provides exposure to different ways in which a
problem could be solved – “You can see how other students go about to solve a problem, you learn more ways in which a problem could be solved.”

Disadvantages of working in a pair

Two sub-themes emerged:

Choosing your own partner; and the role of preparation.

Some students mentioned that they would prefer to choose their own partner with whom they liked to work together. They also mentioned that they preferred to work with someone who was prepared for the test and was committed to perform well. One student also mentioned that he got used to working together and then it was difficult to write the semester test individually. One of the students still preferred working individually if she could not choose her own partner.

The role of preparation before working in a pair

It seems that all students acknowledge the fact that the success of working in pairs depends on the preparation done individually before pairing – “The group is a great advantage if you are prepared”. It is clear that some students did not prepare and relied on the fact that their partner would have the knowledge to assist him/her – “Some of them not even knew what they had to prepare... this is unfair. It is useless to try and work if your partner is not prepared.”

It seems that quite a number of the students did not prepare enough because they knew there will be somebody to help them. They admitted that the students working individually prepared more for the class tests.

Test scores

A summary of the class tests and semester tests scores are given in Table 2. The PPS group did significantly better in the class tests than the control group (d=0.52). This was not unexpected as two people working together should do better than someone working alone, for the following reasons.

- If there is proper cooperation, most of the time the group can be expected to do at least as well as the better one of the two team members would have done on his/her own.

- When working with a partner you interact in additional ways with the problem - verbalising your thoughts, explaining your reasoning, etc. During this process the solution strategy may become clear(er), as mentioned earlier in this paper in the paragraph on pair programming. This effect (even on a person working alone) is mentioned by Wray (2010) and does not happen when a person is working in silence.

- Two individuals may complement each other and create synergy.

We assured students from the start of the semester that neither the control group nor the PPS group would be disadvantaged because they were in a specific group. No statistical significant differences between the semester test scores of the control group and that of the PPS group were found. We assumed that the PPS group would have developed a better understanding of the work and that this would reflect in their semester test scores.
Table 2. A summary of the class tests and semester tests scores.

<table>
<thead>
<tr>
<th>Evaluation</th>
<th>Average</th>
<th>Standard deviation</th>
<th>Statistics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Control group</td>
<td>PPS group</td>
<td>Control group</td>
</tr>
<tr>
<td>Class tests</td>
<td>58.280</td>
<td>66.422</td>
<td>15.632</td>
</tr>
<tr>
<td>Semester tests</td>
<td>54.900</td>
<td>52.401</td>
<td>13.002</td>
</tr>
</tbody>
</table>

*d-value≈0.2 is a small effect, d-value≈0.5 is a medium effect and d-value≈0.8 is a large effect.

We could not use the results of the peer assessments to adjust individual class test scores of the PPS group (as we had wanted to initially), as we continuously struggled to get everybody to submit their peer assessments in time. Also, more importantly, very early on we found that they gave each other unrealistically high ratings. This was probably because they did not want to create ill-will between themselves and their class mates.

In the next section we evaluate the implementation of co-operative learning against the five principles and highlight aspects that may be better managed in the future, and which will be addressed in the next phase of the research.

Evaluation against the five principles of co-operative learning

Positive interdependence - Each student was given a specific role during the tests, either as driver or navigator. Specific roles were allocated to ensure that each group member was dependent on the work of the other. We found that students did not always stick to the roles. As a result, positive interdependence was not always achieved. Academically strong students could complete the test with little input from the other group member. It will be necessary to find an approach to ensure positive interdependence.

Individual accountability - From the questionnaires and interviews it seems that students did not always prepare well for the class tests. If a student who did not prepare for the test was paired with a well-prepared student, he/she was not penalised, because their partner then simply did most of the work. The peer assessment failed to ensure individual accountability and an approach to ensure this principle will have to be found.

Social skills - The questionnaires show that students were initially sceptical about group work, but at the end of the semester they were more positive about group work. This suggests that the students worked well in groups and found it easy to interact. It was also clear by observing them during the tests.

Face-to-face interaction - We found that students generally communicated well with each other without any conflict. They shared resources and supported each other.

Group processing - We continuously struggled to get everybody to submit their peer assessments in time. This is probably because we were slow in implementing the results of the assessments and realised early on that the peer assessments were not a true reflection of what went on in the group. Group processing may perhaps be done more effectively – face-to-face, after the completion of the test.

Reliable peer assessments are an ideal method to determine the individual contribution of each member and will encourage individuals to prepare, contribute and participate. Peer assessments should also impact on the marks obtained for a test.
Conclusions

PPS did not lead to a significant improvement in students’ individual test scores and therefore it is also not clear how much their understanding of difficult concepts improved. However, in the interviews students said that PPS had improved their understanding. In this study we did not investigate why the improved understanding mentioned during the interviews, did not translate into better test scores. It may be worthwhile to investigate this further.

However, at this stage the advantages seem to be in another area.

It was possible to let students experience the advantages of working in groups in such a way that 87% of them indicated that they would prefer to work in pairs again. Also, during the interviews, five of the six students were positive about working in pairs. The sixth student was already studying with a friend and was therefore not against working in pairs – only against the fact that she could not choose her partner. Getting students to prepare better would probably also make someone like her more positive towards PPS.

We were not able to ensure individual accountability and positive interdependence. The main reason the peer assessment system failed to ensure that, was that students probably did not want to create any ill-will by giving their partner a low rating even if they deserved it. Measures will have to be put in place to ensure that these two principles are met.

The intention of the open-book test was to promote interaction and enable students to use different resources to solve problems. It seems that preparation could have been neglected due to the availability of the textbook and notes – where they could identify similar problems.

We are confident that as this project continues, we will be able to find ways of applying the five principles of co-operative learning and that PPS can lead to a significant improvement in understanding and mastering Thermodynamics.

References


The Holes in the Cheese: Improving Engineering Students’ Generic Communicative Competencies

Mark van Ryneveld¹, Zach Simpson², Nickey Janse van Rensburg³, Esther Farron⁴ and Diana Menachemson⁵

¹-⁴ Engineering Education, University of Johannesburg, South Africa; ³ Department of Mechanical Engineering Science, University of Johannesburg, South Africa

¹markvr@uj.ac.za, ²zsimpson@uj.ac.za, ³nickeyjvr@uj.ac.za, ⁴efarron@gmail.com, ⁵dmenachemson@gmail.com

Abstract

Engineers spend considerable time communicating technical details to various audiences. This requires communicative competence which is linked to the underlying knowledge and skills in the engineering disciplines.

The metaphor ‘holes in the cheese’ is used to describe a particular group of reading and writing competencies which are not yet adequately developed in students, but which are expected to be in place at their educational level, and which are further characterised as follows: (a) while it is reasonable to include limited revision of prior topics or competencies in a mainstream programme, substantive interventions to address them must be extra-curricular; (b) a significant proportion of students require development in this regard; (c) they are seldom explicitly taught; (d) most engineering academics are not explicitly trained to identify or address them; (e) identifying and addressing them through traditional assessment of written work (‘red ink’) is time-consuming for academics; (f) moreover, addressing them through traditional assessment is seldom successful: while the document may have been corrected, an improvement in competence is seldom established by this method.

By way of evidence, this paper attempts to name, explain and illustrate these ‘holes in the cheese’ in terms that are sufficiently explicit and concrete so that fellow engineering academics can readily understand and relate to them. This evidence is illustrative and anecdotal, serving as a point of discussion rather than a conclusion of fact.

With regard to reading fluency and comprehension, the reading speeds of students on intake to supplementary interventions, over a three year period, have typically been below the reading speeds regarded as a lower threshold for university students when reading fiction and non-technical materials. With regard to writing, typical challenges include grammatical errors as well as structure, organisation, logic, and integration / synthesis of information from multiple sources.

Introduction

McLeod and Reynolds (2007) argue that we are teaching and learning in times of overwhelming changes in the way we know, the way we teach and in what is expected of us as educators and learners. This is no less true in engineering education. Regardless of whether our teaching and learning environment has in fact changed or whether it is simply our perception of that environment that has changed, it is the anecdotal observation of the authors over a period of about five years that - certainly in the four-year engineering degree programmes offered at the University of Johannesburg (UJ) - a significant number of senior students (nominally between the 2nd and 4th year of study) face particular challenges that were either not faced by their predecessors or were not noticed before. Over that same period, the
throughput rates on the mainstream programmes – measured as the percentage of students in a starting cohort who ever graduate – appears to be falling from around 40 to 50% for cohorts starting six or seven years ago to - from what can be observed at this stage - about 30 to 40% for cohorts of the past two or three years (Van Ryneveld and Wallis, 2010). To use a well-known metaphor, then, the cheese appears to have been moved. This paper attempts to name, explain and illustrate the challenges students face with regard to academic literacies, which admittedly is only one facet of the challenge engineering educators and students face.

There is increasing international recognition of the need for communicative competence in virtually all fields of industry (Sulcas & English, 2010). This is also the case in Engineering where much of an engineer’s time is spent communicating technical details to various audiences (Ostheimer & White, 2005). For the purpose of this paper, generic communicative competence is linked to the underlying knowledge and skills in the engineering disciplines. Analysis of the Engineering Council of South Africa’s (ECSA’s) exit level outcomes (ELOs) identified three categories of literacy practices that should be engaged with during the tertiary education of engineers (Simpson & Van Ryneveld, 2010):

- Reading (including reading an array of text types; discerning essential from non-essential information; comprehending, summarising, paraphrasing, synthesising and referencing information from various sources);
- Writing (including language competence; audience-awareness; genre- or purpose-awareness); and
- Critical thinking (including argument, evaluation and reasoning; reflection and independent learning; relational and analytical thinking).

Of these three categories, the ‘holes in the cheese’ focus primarily on the first two, as there is more opportunity for the development of the third category – critical thinking – at university level.

This paper begins with a fuller definition of what is meant by the ‘holes in the cheese’. Thereafter, it examines the ‘holes in the cheese’ through the particular lens of the academic literacies literature. Included in this section is background about the Engineering Education initiative at UJ. The following section discusses the particular difficulties our students appear to face with regard to reading and writing. This discussion is supported by evidence and examples from our experiences with students. However, it is important to note at this point that this data is merely illustrative and anecdotal; it serves as a point of discussion rather than a conclusion of fact. Our concern is primarily to name, explain and illustrate the challenges students face in terms that are sufficiently explicit and concrete that fellow engineering academics from a range of disciplines (e.g. mechanical/civil) and sub-disciplines within engineering (e.g. structures/transportation for civil) can readily understand and relate to them. The paper concludes with tentative examples of interventions which may be implemented in order to assist students in developing the literacy practices required for engineering study and work.

Defining the ‘holes in the cheese’

According to Crawley, Malmqvist, Ostlund and Brodeur (2007), “[engineering] students must learn how to merge the physical, life, and information sciences at the nano-, meso-, micro- and macro- scales; embrace professional ethics and social responsibility, be creative and innovative, and write and communicate well. Our students should be prepared to live and work as global citizens, [and] understand how engineers contribute to society”. All of the
important expectations expressed in this statement represent the anticipated ‘product’ of an Engineering degree programme. However, it is difficult to match up to these expectations if generic communicative competencies are not in place. Herein lies the relevance of the analogy alluded to in the title of this paper. Reading and writing competence, if not developed within the course of university degree curricula, can become holes in the cheese that detract from the technical quality of the graduates from those degree programmes.

The literature is clear on the fact that communicative competencies are important. For example, the World Chemical Engineering Council (2004, in Crawley et al, 2007) developed lists both of engineering graduates’ most significant shortcomings and of the most important abilities for engineering graduates to possess. Effective communication is the only ability to feature prominently on both of these lists. That is to say, while it is considered one of the most important abilities with respect to employment, it is one of the greatest deficits with regard to education. Similarly, the Massachusetts Institute of Technology (also in Crawley et al, 2007) conducted a survey of lecturers, professionals and alumni aimed at ascertaining the relative importance of a number of skills for engineering graduates. Again, these results placed communication among the most important skills necessary (along with reasoning, analysis and teamwork). In another study (reported on by Sulcas & English, 2010), effective communication was rated as the second most important skill in engineering after problem solving.

Reading and writing competence is important both after graduation and during students’ studies. This is because writing is one of the primary means by which students are evaluated (Angelil-Carter, 2000) and because reading is one of the primary means by which students are expected to acquire information which can be used to construct knowledge. As Evers, Rush & Berdrow (1998) argue, there is little point focusing on technical engineering content if students’ reading and writing competence is so poor as to prevent the comprehension and communication of the content. As such, while questions of reading and writing competence may not be an explicit focus of engineering curricula, they are nonetheless vital as they have the potential to hinder students’ achievement of the learning objectives of these curricula. As Dempster and Reddy (2007) argue: it is impossible to learn effectively (or at all) without the necessary language skills to do so. The longer these competencies remain under-developed, the more glaring these holes in the cheese become. What this means is that communicative competence appears to be both required and taken for granted within engineering disciplines. However, when it is absent, engineers appear to lack the tools to be explicit in addressing this teaching and learning challenge.

For the purposes of this paper, the ‘holes in the cheese’ are defined as particular competencies which are not yet adequately developed in students, but which are expected to be in place at their particular educational level. It is the observation of the authors that these ‘holes in the cheese’ have a number of other general characteristics:

- It is reasonable and appropriate to include a limited amount of revision of prior topics or competencies in a mainstream programme, before proceeding to new subjects. However, any substantive interventions to address them must be extra-curricular. ECSA is explicit in this regard that ‘...[p]reparatory or remedial courses are not included in the [specified minimum number of credits that make up a particular programme]...’ (ECSA, 2011).

- A significant proportion of students require input into the development of communicative competence.
• Communicative competencies and literacy practices are seldom explicitly taught.
• Most engineering academics are not explicitly trained either to identify or to address communicative competency.
• Identifying and correcting them through traditional assessment of written work (‘red ink’) is extremely time-consuming for academics. One suspects that partly for this reason, it is often not done, and is therefore often not reflected explicitly in the allocation of marks.
• Moreover, correcting them through traditional assessment of written work is seldom successful: While the document may have been corrected, an improvement in competence is seldom established by this method.

An Academic Literacies perspective on the ‘holes in the cheese’

Lea and Street (1998) propose three approaches to the development of student academic literacy. The first approach is an academic skills approach. This approach is similar to Street’s (1984) autonomous model of literacy, which maintains that literacy is acquired through learning a discrete set of skills that are transferable across varying contexts. The second approach, academic socialization, focuses on academic disciplines as unique ‘cultures’ and requires that students be inducted into these disciplinary cultures. The third approach, advocated by Lea and Street, and many others since, is termed academic literacies. It stems from an acknowledgement that literacy is a social practice, that is, that it is made manifest differently across varying social contexts and that the literacy practices employed within academic communities are a result of the dominant power-relations within that community.

However, as Archer (2010) argues, each of the three approaches in the Lea and Street model of academic literacies encapsulates the others; as such, they are not mutually exclusive and nor are they linear stages of progression. Archer (2010) further argues that the academic literacies approach is better suited to advanced students and can be seen as the end of a process rather than the beginning. This research is conducted within the framework of the Lea and Street model but is located at the beginning of that process, rather than the end. It examines the basic communicative competencies upon which academic literacies are supposed to be developed. As Bartholomae (1985) argues, the higher the level of competence required, the fewer general cognitive strategies there are; that is to say, writing, thinking and learning become increasingly field specific as students progress through their academic careers. With this in mind, this paper is not concerned with the specific discursive practices of the engineering disciplines per se, but the more generic communicative competencies upon which the discourse/s of the engineering disciplines is founded.

In addition, one of the goals of this paper is to begin the process of interrogating what the academic literacies model means, in practice, for engineering education in South Africa. The notion of academic literacies appears not to have been adequately explained within an engineering context. It is the observation of the authors that what appears to be commonly understood in the academic literacies community appears not to be as well-known to engineering academics – at least not within the UJ context.

The academic literacies perspective locates student challenges with academic literacy within various contextual factors. As such, addressing the challenge of student writing requires an understanding of the culture of the various disciplines as well as the dominant knowledge-making practices within those disciplines (Lea and Stierer, 2000). However, this leads to
what Archer (2010) calls the double-bind that ensnares university educators. This is due to the simultaneous pull towards ensuring learners conform to institutional expectations while also attempting to allow students from diverse literacy backgrounds to achieve success in the institution. Archer (2010) refers to this as the access paradox where the key question is how to provide access to dominant forms of meaning-making while at the same time valuing the diversity of resources our students and our societies bring to the educational experience.

It is one of the aims of the Engineering Education initiative at UJ to address these issues. The initiative was established in 2009 in order to pursue specialist engineering education matters from within engineering so as to complement the approaches of Academic Development. To this end, the focus has been on the higher years of study rather than on the school/university interface (in line with the recommendation of Jacobs, 2007). As part of the initiative, an academic literacies practitioner was appointed as a subject specialist within one of the engineering departments. The rationale for such an appointment was to assist with the integration of academic literacies into the mainstream engineering programmes.

The particular context of engineering poses three challenges to the implementation of an academic literacies model. Firstly, it is typical of engineering programmes for the curriculum to be ‘jammed’, meaning that time is at a premium to cover what is considered to be necessary content. Secondly, the curriculum is strongly loaded towards maths problem-solving courses at the expense of writing-intensive courses. Thirdly, students in engineering (at UJ at least) tend to begin to take writing-intensive courses only in their third year of study, the tacit assumption being that basic communicative competencies are already in place by the time students progress to the senior years. In reality, this lack of practice with regards to academic literacies poses significant challenges to students in their final year research projects, when it is extremely difficult to address these challenges.

It is thus evident that the structure of the curriculum does not strongly support the development of student academic literacies. Nevertheless, students are expected to communicate the findings of their studies both orally and in writing through tests and exams, essays, reports, and presentations. Communicative proficiency also forms part of the ECSA ELOs, with students being expected to communicate effectively, both orally and in writing, with engineering audiences and the community at large. These expectations may be further strengthened by international trends: either explicitly or implicitly, both the American Society of Civil Engineers (ASCE) and the American Society of Mechanical Engineers have identified priority goals for their professions which broadly require improved communicative competence (ASCE, 2008 and ASME, 2008). In addition, communicative proficiency is critical to learning in quantitative areas as well as qualitative areas (Simpson and Van Ryneveld, 2010; Howie, 2003). As such, academic literacies ‘punch above their weight’ in a curriculum that, in terms of credit allocations, strongly favours maths problem-solving courses.

In conclusion, as Lillis (2001) argues, in order to be successful, students must learn the conventions of and gain access to the literacy practices of, in this case, engineering. However, these literacy practices are often taken for granted and are surrounded by “institutional mystery”. This paper does not seek to posit solutions to this paradox; instead, it outlines the challenges students face as a point of departure for addressing this paradox. This point of departure stems from two key assumptions. First, as Jacobs (2007) argues, while students tend to gain expertise in the content of academic disciplines, they often fail to gain expertise in the rhetorical processes by which that content is created and communicated. Second, the development of student literacies is not solely dependent on students’ individual
actions, but also depends on the developmental opportunities offered by their environment (Norton and Toohey, 2001).

**Where are the ‘holes in the cheese’?**

This section provides evidence to name, explain and illustrate the ‘holes in the cheese’ with respect to communicative competence. The illustrations have been compiled by the authors over a period of three years from student work in both formal coursework and informal supplementary support interventions (‘informal’ used here to mean that they are not part of the university curriculum), with students drawn from all engineering disciplines, and spread over the senior years (2nd to 4th year). There is no intention in this paper to differentiate between years of study or disciplines. Rather the intention is to name, explain and illustrate, in general terms, the academic literacy challenges evident across this broad group of students.

One overall indicator of the ‘holes in the cheese’ is demonstrated by the results of the PTEEP test (Placement Test in English for Educational Purposes) of the University of Cape Town’s AARP (Alternative Admissions Research Project) suite, normally used for benchmarking students on admission to university. On this test, carried out on a group of about 100 students on a BEng/BIng programme in their 3rd year of study, about 35 to 40% of the group recorded PTEEP scores below the ‘proficient’ level. The PTEEP is generally used to test first year students (sometimes for admission or placement purposes) and the fact that third year engineering students are failing to achieve ‘proficiency’ on this test, suggests that very little development of these competencies is taking place during the programme. This may also be a contributing factor towards the fact that many Engineering students struggle to complete their studies in the prescribed time. This is supported by Howie (2003) who found, albeit at school level, that language proficiency plays an important role in determining success in mathematics.

More specific examples of the ‘holes in the cheese’ within the categories of reading and writing have been observed and measured through individualised supplementary support interventions over a period of three years with about 25 BEng/BIng students between 2nd and 4th year of study. These interventions were undertaken with volunteer students across Civil and Mechanical Engineering and were conducted with small groups of students over the period of one semester. Although undertaken in small groups, the presence of at least two facilitators ensured a degree of individualised instruction for each student. One of the aims of these voluntary supplemental classes was the development of students’ reading speed. Measurement of reading speeds was undertaken through proprietary software (Reader’s Edge). Each reading speed test in this software package is followed by a series of short multiple choice questions on the passage read. The proportion of questions answered correctly is then applied to the raw reading speed to obtain an effective reading speed (which are the figures reported).

Reading speeds of students on intake to these supplementary interventions, over a three year period, have typically ranged between 60 and 160 words a minute. This is at a level of difficulty that would be considered to be below Grade 12 school level. Comprehension on this level ranged from 50 to 100%. This is well below the 250 words a minute regarded as a lower threshold for university students when reading fiction and non-technical materials (Cambridge University Students Union, 2011).

Voluntary online reading speed tests were also completed by the 2011 third year cohort of engineering degree students across the Faculty. These reading speed tests were again conducted using the Reader’s Edge software. Approximately two-thirds of the cohort
completed the tests. The results indicate that around 80% of the cohort were unable to read at 250 words per minute as per the above-mentioned guideline. Figure 2 illustrates the distribution and cumulative distribution of the reading speed test results.

![Figure 2. Distribution and cumulative distribution of effective reading speed of 3rd year cohort of engineering students](image)

Reading fluency and comprehension are important considerations for student success. This is because it influences students’ ability to keep up with work load and understand the highly technical nature of engineering content. Kalman (2008) argues that reading material in engineering textbooks is one of the major obstacles that face our students. Kalman goes on to argue that obstacles such as this can only be overcome through a holistic approach to developing student competencies which may include classroom-based intervention. Furthermore, as implied in the very title of this paper, a lack of reading fluency and comprehension prevents students from understanding engineering content as what Elder (2009) calls a “mode of thought” rather than as fragmented bits of information.

In addition to reading speed, the voluntary supplemental classes described above also aimed to develop students’ written English language competency. In the written work they produced in these classes, typical difficulties experienced are indicated in Table 1. These are basic linguistic challenges but they can detract from students’ overall success – as students and as graduates. In addition to these challenges around language proficiency, the authors, through close observation of the students’ engagement in literacy activities, also noted a number of challenges relating to the students’ mastery of academic literacy practices. For example, it was noted that the students did not undertake advance planning when they wrote reports. It was further observed that a basic problem that many of the students encountered was extracting key words or ideas from the materials presented and it was further necessary to teach planning skills such as mind-mapping. The authors also noted that the students did little to no revision and editing, instead writing their ideas in a ‘stream of consciousness’ manner, that is, in a random order without focussing on the point of the written work. Many of the students were also unfamiliar with the passive tense and, as such, were unable to depersonalise their writing.

Two key points stand out from the experience of these supplementary voluntary interventions: firstly, it is difficult to give these competencies the attention they need within traditional university modules given the mismatch between the level of material to be covered and the level at which these competencies need to be addressed. Secondly, ECSA does not permit significant “make-up” material to be included in curriculum credits. As such, while it
is desirable to integrate the development of these competencies into the curriculum, a variety of integrated and complementary approaches may be necessary.

**Table 1.** Typical examples of language errors made by students.

<table>
<thead>
<tr>
<th>Type of Error</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tense</td>
<td>“When I came to the university the medium of instruction is English” “The mountain glaciers are decreasing, desertification was growing exponentially, an increase in degraded coastal areas and the list goes on”</td>
</tr>
<tr>
<td>Concord</td>
<td>“There are a lot of things that makes me want to be a civil engineer” “I now realise that not only rural areas needs developments”</td>
</tr>
<tr>
<td>Misuse of pronouns</td>
<td>“It is known that one has to know their English before they become good writers” “I’m a person who loves doing things on their own”</td>
</tr>
<tr>
<td>Misuse of verb forms</td>
<td>“Engineering is one of the most paying industries in the world” “Then thus I am committed myself to use the occasion of this assistance program”</td>
</tr>
<tr>
<td>Inability to express ideas clearly</td>
<td>“Engineering has a lot to do with calculations than the theory reports writing” “I need to be able to come up with the most simple and possible ways in solving problems and not make them simpler”</td>
</tr>
<tr>
<td>Incorrect vocabulary</td>
<td>“As a full time student, I am enrolling every day...”</td>
</tr>
<tr>
<td>Sentence construction</td>
<td>“... a slum is defined by any one of five deprivations, these deprivations are...” “And it will also help as to research and gather a lot of information in the different sector”</td>
</tr>
<tr>
<td>Colloquialisms</td>
<td>“I have found that this keeps me in tune with industry trends and as a result I have now made it part and parcel of my weekly activities”</td>
</tr>
<tr>
<td>Repetition</td>
<td>“... would be good for any person and could help a person in all walks of life”</td>
</tr>
</tbody>
</table>

The challenges students face with regard to generic communicative competencies can also be seen in practical examples of student work drawn from courses in Mechanical and Civil Engineering. For example, the text in Figure 3 is a brief, one-page essay produced in class by a senior Civil Engineering student. The essay has been typed ‘as is’. The topic for the essay was the importance of infrastructure asset management in addressing the poor state of municipal infrastructure in South Africa, using the water services sector as an example. It is evident in the example text provided that many of the same problems with grammar and syntax described above can also be identified here. However, there are other concerns evident in this particular student essay that illustrate key challenges a student such as this experiences in terms of reading and writing. The discussion that follows is an outcome of a process of reflection undertaken by the lecturer involved.

The first concern is the students’ lack of comprehension of material he has read. The essay contains numerous attempts to integrate what he has previously read with the topic given. For example, the opening sentence of the essay is an attempt to provide a definition of ‘built environment infrastructure’ which the student has misinterpreted as ‘building environmental infrastructure’. One of the aims of the course in which this essay was written is to encourage
students to interrogate how engineering activity is impacted upon by the full range of social, economic, political and environmental factors at play in a country such as South Africa. The student’s attempt to do so largely fails – in part because of a lack of comprehension of the materials he has read.

Building an environmental infrastructure is part of a nation’s capital stock that produce services that are consumed by members. Infrastructure supports the quality of life and the economy. I will now discuss the Infrastructure Asset Management (IAM) to address the poor state of infrastructure.

The Infrastructure Asset Management (IAM) is defined by a formal approach to the planning and practice of responsible municipal asset management, which is to ensure quality that last longer, which is cost-effective and sustainable to the community.

As the water sector plays a big role in South Africa as a poor infrastructure, is due to the amount of people not having a sufficient, durable, effective supply of water for irrigation and sanitation. To address these problem which contribute to the inequality of SA is by gathering a sufficient amount of information of the problem like, its functionality, effectiveness, performance, management and cost.

South Africa is still seen as a developing country as it have a high population growth, low economic activity and high inequality, this all contribute to an individual’s health and prospects.

The water that is being provided to SA community should be a sustainable infrastructure to allow that every person could have fresh water and sanitation facilities. This by great infrastructure planning one could ensure that sanitation and fresh water is supplied equally to the growth rate. Doing this have huge cost implications that the government could not spend due to the nation’s growth rate and that only 33% of people contributes to the economy.

This by ensuring and allowing business development within a community and getting private investors this could be possible.

By improving the asset management infrastructure would allow SA to meet key regulatory requirements, more productive relationships between parties as it also improve the credit rating. This will contribute to SA becoming a first world country.

Figure 3. Text produced by a senior Civil Engineering student.

A further concern in this particular essay is the student’s ability to logically develop and link thoughts and ideas in writing. For example, the third paragraph begins with a description of the poor state of infrastructure in the water sector in South Africa. Rather than elaborating on this with examples, the student then attempts to argue that more systematic infrastructure management can address this problem (by gathering information on functionality, effectiveness etc.). The next paragraph then moves on to a separate issue, namely, the economic challenges facing South Africa. While all three of these points warrant development in this essay, the student has failed to logically connect them in a way that allows the reader to understand the relationship between the poor state of water services infrastructure, the need for information on infrastructural assets and the challenge presented by South Africa’s developing economic state. As such, it is evident that this student (and others) lacks understanding of the ways in which written language works (through paragraphing, coherence and cohesion) to systematically organise thoughts and ideas in ways that help readers to easily follow the logic of what has been written.

Similarly, in the context of Mechanical Engineering, Figure 4 provides an example of a 600 word essay written by a senior Mechanical Engineering student on South Africa’s role in global mineral production. Once again, the discussion below is an outcome of reflection undertaken on the part of the lecturer of the course.

Although not common, many of the students failed to adequately address the given question, which ultimately negatively affected their grades. This was despite the fact that the students were provided with assessment rubrics which outlined the assessment criteria. The students appeared to struggle to demonstrate an understanding of the subject in question, where
random and unrelated theories were presented to support unstructured arguments. In addition, common problems which students appeared to encounter involved structuring reports in a coherent and logical composition. Students also appeared to find it difficult to organise their thoughts.

While South Africa is as rich as it is economically as a result of its mineral patches it is also hindered greatly in that it export raw materials and not process goods. The exports around 50-60% of it’s raw minerals. It’s massive economic blow to the country as most of its industrial potential isn’t being utilized to the best of its ability. It is the goal of the country to become world’s biggest exporters when it comes to finished goods rather than raw materials as it will launch South Africa in to becoming a first world class country.

Africa is known for it’s rich mineral reservoir, and one of it’s biggest producer of mineral wealth in South Africa. South Africa is one of the world’s biggest mineral suppliers, it’s extremely mineraly rich geological landmasses provide significantly to the countries international wealth. [1]

South Africa has been between 85 to 90% of the world’s platinum metal, which is also the world’s most expensive industrial metal on the world market. [2]

It supplies a lot of other mineral and ranked number 1 and 2 for Manganese, Chromium, gold, vanadium and alumina-silicates along with non-metal materials such as Coal. The world rely heavily on the exploitation of South African Raw material export to fuel the production industry. The countries rich mineral sources come from a lot of rich underground and vast geological construct made of multiple mineral rock formation scaling over massive distance. [3]

The Bushveld Igneous Complex is such a construction, and a lone spans over 60000Km$^2$ and is responsible for having the highest concentrate of a Platinum metals in the world. The occurrence of Complex as rich as these have resulted in a very expansive and heavily monitored mining industry in the country and there is a high demand of people of a mixture of professions to be involved as development of the industry will enrich the country radically. For the engineering stand point, not only is their need to derive new ways of obtaining raw materials, but their is also need for refining the raw materials it repeatedly exports, as this has a great affect on the countries potential.

Figure 4: Text produced by a senior Mechanical Engineering student.

Once again, it appeared that the student(s) in question struggled to adhere to basic academic literacy expectations, reinforcing the notion that these literacy practices warrant development within curricula. Paxton (2007) argues that very few students enter their university education having mastered the “academic discourses” of higher education, that is, the rules that dictate how things should be written at university. Paxton continues that, as students enter higher education, they embark on a process of “interim literacies” where they begin to learn these rules.

**Intervention**

As stated above, the aim of this paper is merely to draw attention to the challenges that engineering students face with regard to the development of basic academic literacies. However, in this brief section, tentative suggestions are made that may go some way towards overcoming these challenges. It would appear that the ‘holes in the cheese’ may best be addressed within course content through innovative teaching and assessment practices. However, to supplement this, Engineering Education at UJ has piloted three extra-curricular programs in order to address this challenge.

- Self-paced use of a range of interactive computer software aimed at developing reading and writing competence, and critical thinking skills.
- Individualised instruction by professional reading and writing instructors using the same or similar computer software.
- ‘Writing supervisors’ to work alongside traditional supervisors in guiding students in preparing their final-year research report.
Conclusion

Most academic staff value clear and effective written and oral communication across the curriculum. Despite constraints on the curriculum and on academic staff time (Jackson, Meyer, & Parkinson, 2006), a range of integrated and complementary interventions appears necessary in order to develop students as communication practitioners. The argument presented in this paper can be summarised as follows:

(1) Communicative proficiency is gathering importance in all fields of industry, including Engineering.

(2) However, students need to be inducted into disciplinary content as well as the academic literacy practices of those disciplines, which depends on affording them opportunities to develop these practices.

(3) In terms of reading, a number of students struggle to read texts with the fluency and comprehension expected at university level.

(4) Similarly, with regard to writing, examples of student writing produced by senior engineering students demonstrate a number of concerns with regard to academic literacies.

(5) It is thus necessary that engineering educators engage with the challenge of developing academic literacies (the ‘holes in the cheese’), both explicitly and within the context of the discipline.

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The Performance and Persistence of Engineering Students on their Journey through the First Year

Marietjie Vosloo
Sasol Inzalo Foundation, South Africa
maria.vosloo@sasol.com

Abstract
The Sasol Inzalo Foundation awarded 75 bursaries to performing but disadvantaged students for first year studies in mainstream engineering courses at 7 universities across South Africa. In addition to background data about the students, quantitative assessments of the students’ knowledge and academic performance were combined for analysis with qualitative indicators of skills and affective aspects gathered from narrative material contributed by the students. Five groups of students were identified in terms of their end-of-year results; the groups are contrasted in terms of a range of factors and the journey of each group traced through the first year. The groups experienced very different journeys in terms of performance, metacognition, identification with course of study and affective factors like resilience. One group failed the first year but was allowed to repeat; their performance is significantly improved in the first quarter of their second attempt at first year.

Context
The Sasol Inzalo Foundation was set up to focus on skills development and capacity building for South Africa, in the critical areas of mathematics, science and technology; one of its mandates are to create tertiary opportunities for South African talent from diverse backgrounds in the fields of Science, Technology, Engineering and Mathematics.

At the beginning of 2010 the Foundation awarded 99 bursaries to undergraduate students in mainstream programmes in science or engineering; this was followed in 2011 with a second cohort of 92 bursars. 75 of the 2010 bursaries were awarded to first year engineering students at seven universities across South Africa. Selection criteria for these bursaries were geared toward providing university access to mainstream programmes for performing but disadvantaged students; in addition to requiring high levels of matric performance and considering a means test, an aggregate score was calculated which weighed performance according to how resource-poor the environment was from which the student originated. The profile of the selected student group closely matches the national demographic profile.

The students received comprehensive financial, academic and psycho-social support. This included residential seminars focused on improving their understanding of threshold concepts in mathematics and science, as well as soft skills development. A peer mentoring system was introduced and access to a wellness counselling service arranged. The support programmes for 2011 were adapted based on the outcomes found in 2010.

Both cohorts of students have been tracked extensively from the time when they applied for the bursaries to the present. Author and Blignaut (2010) reported on the journey of the first cohort early in the second semester of 2010; the present paper tracks the engineering students, a subset of that cohort, further to the end of their first year and through the transition into the second year of their engineering studies.

Theoretical framework and links to international and South African literature
The framework for this study was developed from a review of international (e.g. Parkin 2009), and South African (e.g. Rollnick 2010; Letseka et al 2009) literature on student throughput, the first year experience (e.g. Jorgensen-Earp and Staton 1993), departure models (Tinto 1975, 1987 and similar models, Draper 2008), under-preparedness (Brüssow 2007) and factors influencing university success.

The notion of success at university was studied in relation to three dimensions, namely cognitive elements, such as knowledge, conceptual understanding and academic literacy; skills, such as language, study methods, approach to learning (Case and Gunstone 2006) and time management, and affective aspects, such as identity (Ghee 2000), agency (Bandura 2006), social integration and resilience (sense of coherence (Antonovsky, 1998b), thriving (Carver 1998, p. 246) and hardness (Kobasa 1982)).

Information about the bursars’ backgrounds, living arrangements etc formed part of the data; some of these factors were found to play an important role in the previous study, and were therefore included as a separate category of analysis in the current study.

HSRC studies (Letseka et al 2009) have cited lack of funding as a primary cause of departure at South African universities. The Foundation bursaries sought to neutralize this factor by providing full-cost bursaries, thereby allowing the study to focus on the influence of non-financial factors on student persistence and performance.

Research approach and description of the analysis

The Foundation follows the precepts of complexity theory and consequently applies integrated qualitative and quantitative approaches (Byrne 2009) in its research. In addition to background data about the students, quantitative assessments of the students’ knowledge and academic performance were combined for analysis with qualitative indicators of skills and affective aspects gathered from narrative material contributed by the students. Narrative data were collected using SenseMaker™ software (SenseMaker™ is a software suite designed to be used as a narrative repository and patterning tool that allows analysis of patterns within the narratives).

Data was collected roughly every quarter from both cohorts of students to track their progress and development, as well as from other groups of students for comparison purposes. This paper will focus on the findings regarding the performance and persistence of the Sasol Inzalo Foundation’s engineering bursars in particular.

Year-end outcomes in terms of persistence and performance

At the end of 2010, 65% of the first cohort was eligible to continue to the next year, having failed at most 2 courses, while 11 of the group were excluded from the programme, having failed outright (Table 1).

Table 1. End-of-year outcome at the end of the first year

<table>
<thead>
<tr>
<th>End of year outcome</th>
<th>Number</th>
<th>Percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passed all subjects</td>
<td>22</td>
<td>29,3</td>
</tr>
<tr>
<td>Eligible to proceed (Failed 1 subject)</td>
<td>13</td>
<td>17,3</td>
</tr>
<tr>
<td>Eligible to proceed (Failed 2 subjects)</td>
<td>12</td>
<td>16,0</td>
</tr>
<tr>
<td>Failed; permission to repeat</td>
<td>17</td>
<td>22,7</td>
</tr>
<tr>
<td>Failed and excluded</td>
<td>11</td>
<td>14,7</td>
</tr>
</tbody>
</table>
Three students left the programme voluntarily, one before June in the first year, one after failing but being allowed to repeat the year and one after passing the first year comfortably, all indicating that engineering wasn’t the right course for them. Of the excluded students, an additional 2 also indicated that they would continue their studies in a different field.

**Cognitive dimension: Comparison between year-end outcomes and matric results and other assessments**

Figure 1 shows the matric and National Benchmark Test (NBT) results of the different groups. All the groups had an average score of above 83% for mathematics in matric, but the group who passed all subjects stood out in terms of their Physical Science matric scores (average of 74.6% as opposed to 68.4% to 70.4% average for the other groups). They also had higher scores for English and higher admission point (APS) scores, i.e. they were overall strong students in terms of matric results. The matric results of the group who at the end of the first year were eligible to proceed after failing two subjects is interesting, however – their matric results showed the second lowest average in Physical science (68.8%), unremarkable English scores, but the second highest average APS score (44.3 opposed to 46.4 for the top group) and a higher average NBT academic literacy score than that of the top group (70.2 compared to 67.6).

![Matric and NBT results](image)

**Figure 1.** Average Matric and National Benchmark Test scores for different groups

As part of the support programme, a winter school was conducted during the June holidays, consisting of an academic programme (conducted by Ukuqonda Institute) during the daytime and soft skills programmes during the evenings. During their interaction with the students, Ukuqonda assessed them on disposition (in terms of engaging with the material) (percentage scale, 100% is highest engagement) and conceptual understanding of the topics being worked with (scale of 1 to 7, 7 being the highest) (see Author and Blignaut (2010) for a description of the categories). The only group that stood out in terms of disposition was the group that was eventually excluded (average of 55.5% as opposed to between 64.5% to 66.3% for the other groups). In terms of conceptual understanding, none of the groups who repeated or were excluded scored above a 5 for conceptual understanding, while only 1 of the 46 students
allowed to continue to the second year had a score below 3. Table 2 shows the average scores for each group.

**Table 2.** Average assessment of students’ disposition and conceptual understanding at midyear of the first year

<table>
<thead>
<tr>
<th>End of year outcome</th>
<th>Disposition</th>
<th>Conceptual understanding</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passed all subjects</td>
<td>64,4</td>
<td>4,7</td>
</tr>
<tr>
<td>Eligible to proceed (Failed 1 subject)</td>
<td>66,3</td>
<td>3,9</td>
</tr>
<tr>
<td>Eligible to proceed (Failed 2 subjects)</td>
<td>64,8</td>
<td>4,3</td>
</tr>
<tr>
<td>Failed; permission to repeat</td>
<td>64,5</td>
<td>3,7</td>
</tr>
<tr>
<td>Failed and excluded</td>
<td>55,5</td>
<td>3,4</td>
</tr>
</tbody>
</table>

**Performance journey through the first year**

Figure 2 shows the average performance of all five groups at different stages. Note that the average performance of the students who passed all subjects in the first year, reflects performance in second year subjects; the average of students who are repeating the first year, reflects performance in their second attempt at first year subjects, while the average performance of students who were allowed to continue but are repeating one or two subjects may reflect performance in a mixture of first and second year subjects.

The 25 students who failed one or two courses but were eligible to proceed, steadily increased their performance from the mid-year results in the first year, into the second year. The 16 students who are repeating the first year are spread across 5 different universities; their average performance is substantially improved the second time round.

![Performance](image)

**Figure 2.** Group averages of average performance at different stages for different groups

**Skills dimension: meta-cognition and approach to learning**

Case and Marshall (2004) and Case and Gunstone (2006) identified different approaches to learning in engineering students and described meta-cognition as the student’s awareness of the approach they are using and the ability to switch to a different strategy when needed. The present author conjectured that the described approaches are special cases of strategies that
consist of a mixture of relying on memory, conceptual understanding and process (e.g. practicing examples); studying different subjects would require different “blends” of these 3 strategies at different times, but that they all have their role to play.

As an example, multiplication can be viewed and has most recently been taught as conceptually being the equivalent of repeated addition; however, Fleisch (2008) has shown examples of work by primary school learners which graphically demonstrate failure to obtain a correct answer when trying to calculate 17 x 6 by repeated addition, due to addition errors creeping in. When teaching subjects in the fields of science or engineering one regularly comes across students who in an examination can argue elegantly from first principles, but do not finish the paper on time, due to a lack of process skills. Learning multiplication tables is an example of relying on memory; however, few people memorize tables beyond 12x12, so what to do when larger numbers have to be multiplied? Multiplication of large numbers clearly requires a procedure or algorithm of some sort to be practical. The author conjectured that most courses would require a mixture of the three strategies, namely conceptual understanding, memory and practice (or process skills) for success, and that students who posses meta-cognitive skills would adapt their approach to learning as they progress through their studies.

To investigate this conjecture, students were asked to indicate their preferred approach to learning on a ternary diagram (or “mixture” diagram, the graphical equivalent of dividing 100 points between 3 alternatives) at each data collection and the averages for each group calculated, resulting in Figure 3.

Students were also asked how well they thought their study methods were working for them. 14 students indicated at mid-year that they did not know what they were doing wrong, but their study methods weren’t working for them anymore; none of these passed all their subjects at the end of the year. Of the 5 students that indicated that their study methods were still working for them, 4 passed all their subjects by the end of the year; 43 of the 75 students indicated that they had had to adapt their study methods by midyear.

The group who passed all their subjects had a fairly specific average approach to learning at midyear, consisting of 19% remembering, 52% conceptual understanding and 28% practicing; in the second semester they adjusted their strategy slightly to practice more, and then stuck to that strategy to the end of the year (19% remembering, 47% understanding and 34% practicing).

The group who failed at the end of the year and were excluded, by contrast, initially relied the most on practicing (average profile of 11% remembering, 42% understanding and 46% practicing). After their poor midyear results, they responded by practicing even more (14% remembering, 33% understanding and 53% practicing), finally trying to understand towards
the end of the year (18% remembering, 58% understanding and 24% practicing); presumably, by then it was too late to catch up.

The group who failed two subjects but were allowed to continue, initially followed a strategy similar to the students who failed the year but were allowed to repeat, but by the end of the year followed an average strategy very similar to the group who passed all their subjects.

It is also noticeable in Figure 3 how similar the approaches of all the groups were towards the end of the year, as if they have all gradually figured out a common approach to learning that “works” for first year engineering. Future work will probe this observation more deeply.

**Affective dimension: identification with course of study**

All the students who left the programme voluntarily indicated that “engineering was not for them”, indicating that career fit is an important factor in persistence. The data suggests that it may also be a contributing factor to performance.

Students were asked to indicate to what extent their experience in their course of study matched their expectations – they were asked to indicate relative proportions of three responses on a ternary diagram, the responses being “I have found my calling”, “It is not what I expected, it is better”, and “It is not what I expected, I am disappointed”. Figure 4 summarizes the responses of the different groups by midyear and at year end.

The students who passed all subjects, stood out as being much more positive about their choice of course of study, with an average of 39% allocated to “not what I expected, but better” in midyear, shifting to an average of 42% allocated to “I have found my calling” by the end of the year. The group who failed and were excluded, allocated an average of 57% to “Not what I expected, I am disappointed”; this allocation persisted to the end of the year. Those who failed 2 subjects but were allowed to continue to the second year allocated an average of 60% to “Not what I expected, I am disappointed” in midyear; in this group this allocation dropped to 42% by the end of the first year with an corresponding increase from 21% to 27% for “Not what I expected but better” and from 17% to 31% to “I have found my calling”.

**Figure 4.** Degree to which experience of course of study matched expectations

**Physical factors: residence**

Author (2010) reported that students living in private residences, or in communes (June average of 48.2% in private residences and 45.8% for those living in communes), performed significantly worse than students living in university residences, with relatives or alone (June average of 56.6% in all three cases). The data unfortunately did not allow the untangling of this effect from other confounding factors, such as the possibility of the students living in
private residences also being the students from townships who had difficulty with understanding the language used in lectures or textbooks, it not being their first language.

The narratives demonstrate that access to university residences in particular and accommodation in general does play a major role in students’ ability to focus on their studies:

Everything was just a mess because I did not get placement at the university residences, so I had to go around looking for a place to stay. The place that I got was far from campus and it was very noisy there, but I had no choice because other places were either full or expensive. I had a lot of catching up to do because while I was looking for a place to stay, lectures had already started and I was behind.

As far as res is concerned, it is much more difficult for a second year to get placement for their 3rd year in a res. So Again, I thought if I was present everywhere, I could better my chances of replacement next year—OVERKILL. I had to strip down my hostel activities to one and hope that would be enough as my academics were taking strain.

Another thing that nearly killed my rhythm was res. Not so much res itself as it was trying to stay there. I’m not sure whether it works the same at other institutions; in order to be legible for a reapplication into your res you must acquire a certain amount of points by participation in organised activities, these range from taking part in sport to attending socials as well as house meetings. Now being a struggling engineering student did not afford me any time to take part in a sport or go out on Wednesday night on top of my “first year duties”. In the end I had to make use of the valuable pre-exam time to put together a participation score in order to qualify for res in the following year—giant mistake. I now know that by attending a few soccer or netball matches in the first quarter as well as doing my first year duties and attending house meeting, I have already built up a good score that—paired with my academics—will guarantee a place in the res. No more last minute scrambling for points.

This year I’m living off-campus which is another battle on its own. Now I don’t really have the resources at my finger tips as I used to last year. I also lost my laptop, which was one of the things I really depended on to study and sometimes entertain me. Lost all my work, now if I ever need to use a computer(which is like always, eng student) I need to go to school.

The affective journey through the first year and into the second year

Author (2010) reported on the experience of the first cohort of Sasol Inzalo Foundation bursars, finding that most of the students experienced a difficult journey, described as “from hero to zero”, in negotiating the transition from high school to university.

Then I began to doubt myself and my purpose. At times I second guessed myself, saying ‘How did I get to UCT? I am not an A student and do not deserve to be here, I am merely a B student’. I began to be depressed and did not see any hope for myself. And as I had been anticipating I failed miserably.

During this year it seemed to me that I had completely lost myself. I didn’t know who this new person was and what she wanted out of life anymore. This happened to me even though I was pretty sure what I wanted out of this year at the start of it. Maybe I never fully comprehended the obstacles that university would pose. I felt totally lost for a very long time. The first time I glimpsed my old, ambitious self again was in the fourth quarter.

I recently found out that I have failed maths for the first semester and that news was very disappointing. I have never come close to failing anything in my life and now I have to fail in my first year of varsity. All I could think of when I found out the news was all the people I let down. My parents would work so hard that I could always have a good education, my other close relatives who see me as a role model, because I always received good results and I was the first grandchild to go and study at a university, to my bursary provider who has showed their faith in me by paying for my studies this year, but most of all I let myself down.
The narratives collected early in the second semester suggested that many had made a turn-around in terms of mindset at midyear. The current paper demonstrates that the turnaround also resulted in improved performance for roughly a third of the students.

Their experience matched a pattern called “immersive experiences” described by Jackson and Campbell (2010) in the context of British students going on the workplace segment of their training. This pattern describes transition experiences in general, resonating with inter alia the experience of doctoral students embarking on their studies in foreign universities (e.g. Hofmeyr (2010)). The midyear break provided the bursars a time for reflection on the events of the first semester during which they had to decide whether to bail out or continue. This period of reflection coincided with the Foundation’s winter seminar, which for some students rebuilt their academic confidence and showed others that it is possible to make friends. Students changed their self-talk and reframed their situation, and started to rebalance their lives, behaving in typical ways described by Jackson and Campbell to climb back to success.

After going back home and attending the Sasol camp my perspective and take on life changed. I remembered why I was at UCT, my passion for developing myself through education was awakened. I learnt how my mind worked through exercises we were given at camp. I began to appreciate my talents again. I believed in myself again and in second semester my positive attitude translated into my marks. I started improving and gaining self confidence. My studying strategy changed. I started looking at effective means of passing. Instead of burying myself into text books, I tried understanding basic concepts taught in class and then putting that to practise in past papers. I learned also to ask for help from people who could help me. In high school I could handle academics by myself but here I learned to admit when I couldn’t understand all by myself. I found tutors and my peers to be of great help. As a result all my marks improved in all the courses that I have been doing.

The narratives collected in the first semester of the second year and the drop in performance for the group that had passed all subjects in the first year suggest that some student experienced a similar, but less dramatic transition at the beginning of the second year.

Yes I am a year older now and have gotten use to the varsity vibe, but that still does not make this year easier than last year. The work load has increased and the level of that is required of me has increased. One has to juggle many things at once to keep afloat.

The first big shock was how much reading is expected of us before the actual lecture. Lecturers assume that you will have done the work already and only attend lectures to ask specific questions otherwise it is very difficult to derive any benefit from attending. And since nothing is covered too thoroughly in the lectures the speed at which chapters are covered is incredibly fast. I didn’t realise this until the first test was scheduled and written and found myself with absolutely no time to prepare adequately which was evident in the marks I obtained.

It is also distressing to see how many repeating students there are in any one of the courses that were doing in some instances they are almost as many as the number of students that made it to second year for that course. It kind of makes me question what my chances actually are of making it through this year.

This time, they responded with more resilience, however:

2nd year (current year) is a lot more different. Everything seems brighter, clearer and manageable. I think I have began to bridge that gap between being a learner and a student, since I am a lot more relaxed, complete work weeks before it needs to be handed in and the best part of all - I am not tired all the time.

This year is my second year and I have learnt a lot from first year. So this year for my first math class test I scored a really low mark(18%). At first I was very discouraged and fearful, but I told myself that I still had a second chance in the following class test. So I worked hard on my math and understanding it and it all paid off because I got 66% for the second class test. If this was the first year me, I would have given up all hope and ended up failing math all together.
Having managed to overcome last year's difficulties has allowed me to put aside my doubts and focus on solving my problems instead of wanting to leave.

Conclusion

The 5 groups identified at the beginning of this paper seem to have had different journeys through the first year into the second:

The group who passed all subjects in the first year: These were overall strong students in matric, whose study methods transferred easily or who could adapt their study methods to what is required at university already during the first semester. Their expectations of their course of study were exceeded and they gradually moved to at least a moderately strong sense of having found their calling during the first year. On average, they experienced a drop in performance going from the first to the first quarter of the second year, however; it will be of interest to monitor the extent to which they recover their performance levels during the year.

The group who failed the first year and were excluded from the programme: These students had high average performance in mathematics in matric, but were not strong in Physical Science or English and had the lowest NBT scores of all the groups; none of them exhibited a conceptual grasp of the topics covered in the winter seminar at a level of above 5 (out of 7) and the group had the lowest average conceptual score. They received the lowest scores for disposition, the extent to which they engaged with the material, during the winter school. They were disappointed in their course of study; it did not match their expectations at midyear and the situation did not improve towards the end of the year. They approached their studies by trying to work many examples; when they realized they were struggling, they increased their efforts to practice more, shifting to a more conceptual approach to learning only towards the end of the year.

The group who failed two subjects but were allowed to continue to the second year: These students had high performance in mathematics, high overall admission point scores and Academic Literacy NBT scores, but did not do particularly well in Physical Science in matric. Their average performance in the first semester was in the low fifties. Their disposition and conceptual understanding scores during the winter seminar were on par with those that passed all subjects, but their approach to learning initially relied more on practicing and less on conceptual understanding than the top group; this shifted by the end of the year. In the second semester their average performance started to improve, first to 55% by year end and then to an average of 59% by the first quarter of the second year (the second year results may include one or two repeated first year subjects together with second year subjects, though, possibly inflating the average performance).

The group who failed the first year but were allowed to repeat it: These students had high mathematics and physical science scores in matric, but NBT and conceptual scores on the low side, not much above those of the group who failed outright. They did not break out of an average performance of 47-48% throughout the first year. When they realized they were struggling, they first allocated more weight to using memory, then started to emphasize understanding towards the end of the year. They allocated about 33% to having found their calling, but their average allocation towards being disappointed climbed to 52% by the end of the year. In the first round of tests the second time they attempted the first year, their performance improved to an average of 65% as compared to 48% the first time round. It will be of interest to track their further performance in their second attempt at first year.
The results demonstrate that first year engineering studies hold out a multi-dimensional challenge and that success depends on much more than academic factors. The importance of systems to support students in their journeys should not be under-estimated if South Africa is to improve its throughput of engineering graduates.

References


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Using Parallel Enquiry-Based Interventions to Engage and Motivate Engineering Students

Peter Willmot¹ and Glynis Perkin²

¹ School of Mechanical & Manufacturing Engineering, Loughborough University, UK; ² Engineering Centre for Excellence in Teaching & Learning, Loughborough University, UK

¹ P.Willmot@lboro.ac.uk, ² G.Perkin@lboro.ac.uk

Abstract

Engineering degrees are predominantly taught by highly skilled engineers and scientists but, like most discipline experts, relatively few of them are ever exposed to significant pedagogical training. The concepts and understanding of what motivates and engages students are generally understood but seldom put into practice. Nevertheless, engagement and retention are becoming increasingly important topics as the demands and expectations of UK students are increasing in line with the much higher tuition charges that are the result of recent government changes in the funding of Higher Education. Furthermore, the mind-sets of twenty-first century students are often mismatched with the expectations of their lecturers, who tend to assume intrinsic career motivation and blame poor performance on a lack of drive or ability. The challenge for universities is to enhance the acquisition of knowledge and skills by providing motivators, beyond that gained by the award of marks.

This paper describes an innovative year-long module for first-year mechanical engineering students, which embraces competitive challenges, student-centred learning activities, problem solving, creative design and skills workshops. The activities sit alongside and provide motivators for the unaltered, traditionally taught engineering science curriculum. The concept has been developing for three years and anecdotal evidence had suggested there were positive benefits, so an independent evaluation was commissioned; funded by a small grant from the UK Higher Education Academy. The evaluation used a mix of qualitative and quantitative methods of enquiry and demonstrated that such interventions can not only inspire students but also help to create improved inter-student and staff-student relationships.

Introduction

The transition to higher education is often difficult and it is known that “Effective transition can help to improve rates of initial retention and ongoing success.” (Thomas, 2009) A survey of first year students’ expectations by Cook and Lackey (1999) found that freshers (first year undergraduates) generally expected their learning experience would not differ greatly from secondary school. Persisting expectations of ‘teaching’ rather than ‘learning’ in an environment that expects and requires learner autonomy can lead students to disengage with study and fall behind before that autonomy is fully developed. Couple this with uninspiring traditional delivery of scientific facts and we have a powerful recipe for failure or withdrawal.

The Higher Education Academy surveyed a large number of students who had withdrawn early from UK universities (Yorke & Longden, 2008). The report cited poor quality of the learning experience as one of the major reasons and this is defined for us by the students own perceptions. Some pointed to their sense of isolation. For many, this was associated with large-scale lectures that allowed little, if any, interaction with academic staff or fellow students. Some commented on the impersonal nature, the difference between University and
secondary school (high school) styles and the presumption that lecturers expected students to adapt instantly to their mode of delivery. Others commented on the lack of opportunities to make friends on their course or of intimidating or unapproachable staff. These comments were unsurprisingly negative given that the survey was of students who had already left their courses.

It was the realisation that young people arrive at university with very a different attitude and range of abilities to those of their forebears and that universities need to adapt to their changing needs that drove the movement for change at Loughborough University. When students do not respond and depart or fail, traditionalists are tempted to blame the students’ lack of dedication or ability so there would have to be some changes in the staff approach as well. The ideas described here are founded in the widely known constructivist educational theory where learners are invited to construct knowledge for themselves, become actively involved and learn how to learn while they learn. This paper describes some of the successes and growing pains that have accompanied the experiment and seeks to evaluate the initiative’s worth.

Revised First-Year Curriculum

Five years of work within the Wolfson School of Mechanical and Manufacturing Engineering at Loughborough University, trialling a number of engagement initiatives, have resulted in significant changes to the first-year curriculum and the inclusion of a new ‘active learning’ module specifically designed to address issues of engagement. The new development sits alongside a largely unchanged curriculum and embraces the idea that the most effective learning takes place when students are motivated. In ‘When Teaching becomes Learning’ (2007), Sotto wrote that motivation is already present in learners but it is a matter of creating situations that enable learners to become actively engaged and to use these experiences to reinforce the necessary fundamental knowledge and skills to support the science. This is more easily said than done but it follows that an effective environment for learning is one where students are truly connected and having fun. According to Malone & Lepper (1987) there are four basic factors needed for intrinsic motivation to occur during a learning activity. They are challenge, curiosity, control and fantasy (encompassing the emotions and the thinking processes of the learner) and these are the features that transform learning into a game. These were the basic principles upon which the EPPS module was built.

Module Activity Descriptions

The new module entitled ‘Engineering Principles and Professional Skills’ is delivered throughout the first academic year and accounts for 20 credits (in the UK, full-time undergraduates must study 120 credits per year). The module is built around four student-centred ‘enquiry-based’ assignments (EBL) of different styles and duration and a programme of appropriate skills workshops. There is also a 1-hour per week lecture programme to provide connectivity and, in some cases, give information; there is no formal examination. The projects are highly active and the major project attracts industrial sponsorship. Details of all the student-centred activities are listed in Table 1.
Table 1. Team Based Assignments

<table>
<thead>
<tr>
<th>Duration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EBL-1 1-day (8 hours)</td>
<td>Competitive Design and Make using simple materials</td>
</tr>
<tr>
<td>EBL-2 1-day (8 hours)</td>
<td>Business Start-up Game</td>
</tr>
<tr>
<td>EBL-3 3-weeks</td>
<td>Vehicle Systems Research Project – create a video documentary</td>
</tr>
<tr>
<td>EBL-4 13-weeks</td>
<td>Competitive Design and Manufacture project – Mechanical Handling</td>
</tr>
</tbody>
</table>

The module has a strong association with the School’s personal tutoring scheme. On arrival, the intake of approximately 150 students is split amongst 24 academics who are designated as personal tutors and who meet with their tutor group of typically six each week. Personal tutors have traditionally provided pastoral and general academic support but enthusiasm for the system has historically been patchy and strong bonds were rarely formed between staff and their tutor group or between the tutor group members themselves. By linking the competitive activities to these groups, we hoped to generate a stronger sense of ownership and camaraderie and to include the staff member wherever possible.

Table 2. Skills Workshops

<table>
<thead>
<tr>
<th>Topic</th>
<th>Duration</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Teambuilding and Resource Management</td>
<td>2 hours</td>
<td>Practical exercise</td>
</tr>
<tr>
<td>Library Skills</td>
<td>2 hours</td>
<td>Practical exercise</td>
</tr>
<tr>
<td>Understanding Learning styles and study skills</td>
<td>2 hours</td>
<td>Practical exercise</td>
</tr>
<tr>
<td>Plagiarism</td>
<td>1-hour</td>
<td>Practical exercise</td>
</tr>
<tr>
<td>Problem Solving</td>
<td>2-hours</td>
<td>Competitive Robotics exercise</td>
</tr>
<tr>
<td>Basic Workshop Skills</td>
<td>2x2-hours</td>
<td>Hands-on workshop training</td>
</tr>
<tr>
<td>Engineering Measurements</td>
<td>2-hours</td>
<td>Practical Laboratory</td>
</tr>
</tbody>
</table>

The small group ‘skills workshops’ listed in table 2 run alongside the student-centred assignments and are timetabled as appropriate across the year: these are activities integrated into the programme, and each one is repeated several times until the whole cohort has taken part.

The teambuilding exercise in week 1 helps to form these teams which have generally begun to function by week 5 which has been designated ‘project week’. EBL-1 and EBL-2 are day-long exercises in tutor-teams during this special week when all lectures and tutorials for other modules are cancelled: it was decided to introduce this break from didactic delivery in the fifth week of the first semester to encourage and excite students who were settling to lectures but evidently starting to become unmotivated and inert. Aside from the fixed activities, this week allows freshers some time to reflect and, perhaps, catch up on other tutorial work.
A short lecture programme provides the glue to integrate all the activities together and provide timely information and necessary background knowledge for the project work but the overriding philosophy is that of student-centred learning where groups are challenged to find out for themselves, so lecturing is kept to a minimum in this module.

Analysis of the Effectiveness of Change

Methodology

Conventional end-of-module feedback is obtained routinely for all modules in the School of Mechanical and Manufacturing Engineering; quantitative data are optically read and free text comments are summarised by the module leaders as a developmental process. Feedback relating to the EPPS module was scrutinised for the academic years 2008/2009 and 2009/10. A web-based survey was made available to students on the module in the academic year 2009/2010 to discover their opinions about the different elements of the module and to determine their levels of engagement.

Student focus groups were undertaken during the academic year 2010/2011 with second year undergraduates who had completed the EPPS module during their first year. The outputs from the focus groups provide qualitative data relating to student engagement with the module, perceptions of the module whilst undertaking it and a reflective opinion from the second year perspective. The focus groups were led by research staff who are independent from the School.

Semi-structured interviews were undertaken with staff who initiated the first year curriculum changes, staff who were conscripted to help with the module and personal tutors who may have observed a change of attitude in their personal tutees. All participating members of staff and students were guaranteed anonymity.

Conventional module feedback

Towards the end of each module, during a timetabled lecture or tutorial session, generic questionnaires are circulated to all attending students. These questionnaires pose questions with multiple-choice ‘Likert’ scaled options for the answers relating to module content, teaching facilities and teaching quality; in addition there is space for students to write comments. It is the random qualitative comments made by the student that are of particular interest here.

In the academic year 2008/2009 there were 62 (51%) completed questionnaires received and in 2009/10, the return rate was slightly higher at 90 (64%). These included a relatively large number on which additional comments had been added (32 in 2010) which suggests a generally interested cohort. The feedback form also asked for comments to be given on how the module could be improved. The written feedback was very positive, in general, with students repeatedly commenting on the Interest they gained by ‘real’ experiences and the enjoyment they gained from the tasks.

Some students wrote strong praise for the module: one said “a superb module and really puts your engineering minds to work” while another wrote “very interesting and a great learning experience”. Some individuals, however, disliked one or other of the elements and several suggestions for improvement were made but the only consistent criticism concerned timing with some project work occurring around exam times. Following this feedback, minor changes were made to the module for the academic year 2010/2011. Of interest amongst the quantitative section were the 82% positive response to the question “Is the module
appropriate for the degree Programme?” and 85% positive response to “Is the module interesting and stimulating?” 70% also agreed that the module had developed their understanding of engineering but 30% were neutral.

**Web-based survey**

The online survey was made available midway through the academic year to current students and sought to determine their opinions of the team-based work while they were undertaking it. The response rate was 53% (76 students). Again, there were both multiple choice and free text questions but, unlike the end-of-module survey where standard questions are used for all modules, these questions were specifically devised for this evaluation.

Comments received indicated that students welcomed the enquiry-based learning and teamwork approach; furthermore, the module successfully encouraged students to meet with and engage with their personal tutors. Prior to this initiative, the longstanding personal tutoring scheme had been patchy at best. The module provides impetus for tutor meetings and the questionnaire enquired how helpful students had found their personal tutor for the EBL3 project: 72% of students responded positively, with 10% describing their personal tutor as ‘enthusiastically helpful’. The group work tasks undertaken during week 5 of semester 1 were described as enjoyable by 76% of the respondents and 80% felt that the group work improved their communication skills.

Students reported that they appreciated being able to “work as a team” and that the projects had enabled them to “bond as a team”. One elaborated; “It allowed team dynamics to really flourish, highlighting everybody’s role in the team well, which should prepare us better for the major project [EBL4]”. Another respondent wrote about being taught to “work better as a team and become better friends as a result.”

**Student focus groups**

During the 2010/2011 academic year three focus groups were run, each comprising of four student volunteers from the second year of the mechanical engineering programme. These students had taken the EPPS module during their first year of study. The participants had entered university immediately after taking ‘A’ Levels in Maths and Sciences, after a gap year or after successfully completing the Loughborough University Science and Engineering foundation course. All participants seemed genuinely interested in the evaluation being undertaken and were keen to speak of their personal experiences of the module.

Interestingly, all of the students had extremely good recall of the module content and made very similar comments about the module. These comments fell into two categories; the group work proved to have been very popular, however, participants felt that some of the lectures were rather boring. They spoke positively of “working on real problems with other people.”

Built into the module is the necessity for students to contact their personal tutors. Participants were asked to explain how they felt about making contact with their personal tutor at the commencement of their first year and whether or not they felt differently about contacting him or her later in the year. None of the students expressed anxiety about contacting their tutor at any time. Gratifyingly, there was considerable praise for personal tutors, for example, “Perfectly approachable, not condescending – a hands on approach, I certainly feel able to go and talk to him”.

Week 5 of semester one is a lecture-free period. Instead of lectures the students undertake two group work assignments, to accommodate all the students the assignments need to be repeated – each student attends for two full days. The students all welcomed this break from
the traditional lecture/tutorial format at a time when they felt their workload was building up and did not experience any difficulties in returning to lectures in week 6. However, their feelings about the actual activities they participated in were varied. A selection of the comments made is shown below:

“The break was good; we could use one this year ... it gave me a chance to catch up on work”. “Returning to lectures in week 6 wasn’t a problem – I just got straight back into it.”. “The group car work was fun. The SimVenture business game was quite good fun too, it’s a fun game with real life lessons”. “The activities were a bit naff”.

In addition to ascertaining whether or not students had found particular components of the module enjoyable and pertinent to their studies the focus groups were questioned about whether they had learned anything about how they learn. With the exception of one student all participants felt that the module had contributed to their understanding of how they learn. Comments made included:

“I’ve realised that for me it’s easier to learn if I’m doing it rather than just sitting in a lecture being told how to do it.”

Students detailed three aspects of the module that they found to be particularly useful. The most cited elements were the major project and in particular ‘their week in the manufacturing workshop’, the project management experience and the group working experience: of this one student commented; “I was put in a group with total strangers, some of them were hard to work with which was difficult but I learned to get on with it.”

Finally, participants were asked for their current opinions of the module, looking back as second year students. The consensus of opinion was that they have a greater appreciation of the module now than when they were undertaking it during their first year. The following comments capture all that was said in the three focus groups.

“When we were doing the module I can remember in week 5 enjoying making the buggy but thinking what’s the point of this. Now looking back [I] would like to do another day like that.” “I think it’s good to change the routine a bit and it’s beneficial to be working as a team, you need to cooperate. Team based things like that are good.” “Thinking back I believe that the group work taught me to voice my opinions but I didn’t realise that at the time. Without the first year module I may not have been so vocal this year.” “Much better than at the time, my main memory of it is the final project, which was the best. I didn’t learn as much from the other tasks though and I wouldn’t cart around chasing marks again because I think the module is designed to help us develop skills that are difficult to measure. It would be great if we could have a similar module in our second year.”

**Staff Interviews**

Individual interviews were undertaken with six staff who are personal tutors and staff who are involved with delivery of this module.

Interviewed members of staff who are personal tutors to EPPS students were asked whether they perceived that this module had had any impact on their tutees. The replies were all positive and indicated that they had a better relationship with their tutees than was previously the case.

“Now I see them more as a group, I used to probably have it half and half as group and individual sessions. I probably have more group sessions now just because of the group activities”. “I facilitate and act as a bit of a motivator for the team”. “I equally provide, in some instances, technical input which may be a little bit beyond their experience at that time so that I can assist them in moving forward and if I’m honest also trying to engender a bit of esprit de corps within the teams so that they actually have a desire to achieve”. “Sometimes, particularly at that stage of their development here they need help to glue together”.

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Personal tutors who are not directly involved with delivery of the module were asked whether or not they were aware of the module content and the aims of the module. All of the interviewed members of staff are aware of the overall module content, if not the detail, and the aims of the module.

“I obviously only interface with a fairly small part of it, the part to do with my personal tutees, so some of the exercises the students work with their personal tutors but there is a lot of the module where the personal tutor doesn’t work with their tutees and obviously those parts I don’t know anything about. Obviously [the module leader] sends through material on it as well so when we were actually getting involved I had a quick look at the module [VLE site] just to see what sort of context we were supposed to be working in”.

Members of staff were asked to describe their initial feelings about the module. All staff, whether they were directly or indirectly involved with the module, replied with positive comments.

This is an expensive game [undergraduate study], we are going to be seeing changes in the customer requirements and clearly the secondary education system has adapted to exam driven achievement, and interpersonal skills etc., are neglected to some degree so I think that’s why I’m positive on this”. “Yes, very much so and I couldn’t understand any staff not being”.

Members of staff who were directly involved with some aspect of the module delivery were asked to comment on their initial feelings about being involved. These were staff who had participated in the week 5 activities. Again, all responses were favourable. “I’m happy to be involved with the module and contribute to it. I’m keen to develop engineers”.

In addition to their first thoughts, members of staff were asked to detail their feelings about the module at the time of the interview and whether their attitude had changed since they first became involved and if so what had influenced this change. All but one of those interviewed had been involved with the module for more than one academic year. Members of staff whose attitude had not changed were asked to explain what it was that convinced them the module was an effective approach, an ineffective approach or why they were unable to determine its effectiveness.

All interviewees cited favourable feelings towards the module at the time of interview and in one case the response reiterated the comments that were made by the students in the focus groups.

“Well I’ve talked to my tutees quite a lot about how they feel about it, because that’s more important really, and they’re very positive. I get the impression that they find it a very useful exercise and it’s also a nice break for them from the academic work but they keep stressing that it’s not just a bit of fun and that they do think they’re learning”. “… they have lots of small niggles about things but generally they’re very positive. I’m supportive as well, I think it [the module] has good aims and it generally succeeds”. “…there are ways that it can be improved but …. it is growing and evolving”.

None of those interviewed had changed their opinion of the module since their initial involvement with it. “The module is an effective approach; the students are engaged, keen, happy and competitive”. Personal tutors were asked whether or not they had noticed a change in attitude of their personal tutees since the introduction of this module and if so what the changes were. Responses to this question were a mixture of yes and unable to say, for example:

“Yes, I think they bond together as a group a lot better. …. I think that’s probably the biggest difference”.

“Unable to say – I’ve only had personal tutees after this module was introduced”.

The perceived advantages and disadvantages, from a staff perspective, were investigated.
Advantages: Students working together in a group environment. Breaking down barriers, between staff and students. A better focus for personal tutors to work with their students. Excellent staff time utilisation.

Disadvantages: The module, particularly Week 5 and the major project in semester 2 is labour intensive for staff. Some interviewees reported no disadvantages.

Finally members of staff were asked if they perceived any benefits or hindrances to student development that could be associated to this module. None of the staff interviewed perceived there to be any hindrances. The following benefits were mentioned:

The opportunity for students to interact. To gain a basic understanding of business and technology. To get them going more quickly. The break from lectures as their work is beginning to pile up. The fun aspect. The valuable experience of group work, early in their course.

Conclusions

Members of staff and students, who were interviewed for this evaluation, view the module as having a positive effect on both student engagement and the development of student group working skills. It was also established that, since the introduction of this module, there had been an improvement in the working relationships between personal tutors and their tutees. Where personal tutors were only visited reluctantly in the past, many students now appear protective about their own group and certainly much keener to ask their tutor’s advice. The introduction of project work into the first year has excited students and unhelpful barriers are being broken down. The role of personal tutor has been extended and we now have tutor-groups competing in the project activities with senior academics taking a keen interest in their group’s successes and providing helpful feedback to develop and improve the learning activities.

The fact that the module exists alongside conventionally taught engineering science modules meant much less disruption than a complete reorganisation would have required and it allows those academics who have been schooled in convention to continue with what is familiar to them. Furthermore, the two curriculum aspects are mutually supportive. The EPPS provides learning skills, demonstrates real applications and encourages engagement with the course and the profession, while the conventional modules add depth, scientific knowledge and mathematical skills that help to reflect on and explain the outcomes of some of the project work that often doesn’t go quite as planned but still provides a substantial learning experience: learning through mistakes.

There were some less favourable comments made by students concerning small individual elements of the module, for example, some disliked one or other of the actual tasks and the marking structure for particular topics (particularly when they had scored badly), however, these perceived shortcomings were not deemed to jeopardise the effectiveness of the module. By far the most common criticism gathered from all survey methods concerned the timing of events and clashes with revision periods etc. With such a large group and the need to operate all the activities several times over on a rota basis, this seems inevitable. Overall, the students considered the benefits of the module vastly outweigh any shortcomings. The module is still in its infancy and is being developed and improved each year and some of the perceived shortcomings have already been remedied.

Finally, there were strong correlations of opinion regarding the benefits of the module between the staff and students who were interviewed and also with the information on the module feedback forms and from the online student survey. All research methods strongly
supported the earlier anecdotal evidence that was instrumental in initiating the evaluation project.

References


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MIGs: Mediated Interaction Groups for Enhancing Learning Among Engineering Students

Laurie Woollacott
School of Chemical and Metallurgical Engineering,
University of the Witwatersrand, South Africa.
lorenzo.woollacott@wits.ac.za

Abstract
This paper describes an innovative, active-learning methodology termed mediated-interaction-groups or MIGs for the enhancement of learning by means of students articulating their ideas and thinking in an interactive learning environment which is strongly mediated by a knowledgeable facilitator. The methodology is designed to enable students in large classes to benefit from discursive interactions in which the student/staff ratio is effectively 4:1 even though the actual ratio is much larger. The class is divided into groups of 15 students but only 4 students engage with the mediator in any one session. This paper presents an evaluation of this arrangement. Three related studies were conducted to investigate how the methodology impacted student learning, how students experienced the methodology, and what educational dynamics were operating in the MIG sessions. Qualitative results indicated that effective learning processes were operating in MIG sessions and that the students were overwhelmingly positive about the intervention. Combining the quantitative and qualitative findings provided strong evidence that the MIG sessions were an effective methodology for enhancing student learning in the context of engineering education in South Africa.

Introduction
The MIG methodology was developed in the context of the first year programme for chemical and metallurgical engineering students at Wits University. The objective was to enhance student learning by means of strongly mediated group discussions. Its development has been described elsewhere (Woollacott, 2011). In this paper, the settled methodology is presented along with the test work that has been undertaken to investigate its effectiveness in achieving its intended objective.

The paper begins with a description of the MIG methodology and a review of relevant literature. Thereafter the findings of three inter-related evaluation studies are presented. The paper concludes with a discussion of the findings and the recommendations that emerge from them.

The MIG Methodology
The MIG format is summarized graphically in Figure 1. It consists of four ‘participants’, about ten ‘observers’ and a strong mediator all seated around a table as shown. The visible activity occurs in the ‘circle of interaction’ and consists of the participants being drawn by the mediator into a discussion around topics relevant to the course material. The participants do most of the talking the idea being that their learning should be enhanced through the process of trying to articulate their thinking in a discursive environment. The next section provides a theoretical justification for this approach.

Each MIG session is of short duration – between 30 and 50 minutes. Observers do not participate actively in the discussion except on rare occasions at the mediator’s discretion. However, from one MIG session to the next, students rotate between being observers and
participants so that over a period of time every student has the opportunity to engage as a participant several times during a semester.

![Figure 1. The MIG Format](image)

**Mediation and facilitation in a MIG session**

The mediator has a double role. The first is to facilitate the session in a way that creates and maintains healthy group dynamics and an environment that is conducive to learning. This is particularly important because the MIG structure puts participants ‘on the spot’ which can lead to embarrassment and awkward situations if the mediator is not alert. The success of the format depends on gaining the trust of the students so that the MIG environment, though pressured, is seen by them to be ‘safe’: students need to feel that it is safe to be wrong and to risk making erroneous statements or judgements.

The second role of the mediator is crucial: the mediation of learning. The intention is to lift the interactions from the level of a facilitated discussion to one where the interactions promote learning and conceptual development as much as possible. This involves more than ensuring that the discussion remains focused and flowing. It requires paying attention to the understandings and perceptions which the MIG participants express and being involved in the discussion in ways that advance, develop or, if necessary, correct the students’ perceptions. At times this will mean asking direct questions, giving comments and ‘nudging’ the focus of the discussion so that the participants engage with their conceptions differently and more deeply. At other times, it will mean encouraging peer discussion and individual explanations, and, if appropriate, drawing these out by calling for elaboration or suggesting a different perspective.

**Theoretical Background**

In the literature on the mediation of learning, three types of context are evident – learner-mediator, learner-peer, and learner-self. In the former context, socio-cultural theories of learning have been cited – in particular Vygotsky (1978) – to explain how the interaction between a mediator and a learner facilitates more extensive learning than would occur if the learner learned alone (Goos, Galbraith, & Renshaw, 2002). The mediator interprets the articulations of the learners and, on this basis, can nudge the learner towards different associations of thought (Vygotsky, 1978; Feuerstein & Feuerstein, 1991). Feuerstein, in particular, has elaborated on what mediators need to do in order to facilitate this (ibid.). In
addition, he argues that when a mediator is effective in facilitating a shift in the understanding of learners in regard to the specifics of a particular learning context, a transformation can also occur in their general level of cognitive functioning (Feuerstein, 1979; Feuerstein & Feuerstein, 1991).

Vygotsky also noted that learning could be enhanced in learner-peer contexts even in the absence of a ‘more-competent-other’: enhancement could potentially occur in groups consisting of peers of similar expertise even though that expertise may be limited – each peer “possessing some knowledge and skill but requiring the others’ contribution in order to make progress” (Goos et al., 2002, p. 195). Goos et al. also noted enhancement of learning brought about by students articulating their thinking in peer group settings through “mutual adjustment and appropriation of ideas rather than a simple transfer of information and skills” (ibid.). Mahalingam et al (2008) describe how verbal interactions facilitate the identification and correction of misconceptions.

Even in the absence of interaction with a peer or a more-competent-other, the act of articulation itself has been shown to enhance learning. Van Lehn and Jones (1993) and Chi et al. (1994) have studied this ‘self-explanation effect’ – where improved learning occurs as students explain to themselves the texts they are reading or the examples they are working through. They found that the primary dynamic that seems to be at play here is ‘gap-filling’ – a process whereby the act of self-explanation uncovers knowledge gaps in the evolving understanding of a student and thereby prompts internal clarification to fill those gaps.

While the enhancement of learning in the ways just described is clearly supported in the literature, there are also reports of instances where such enhancement did not occur. The articulation of student thinking in group interactions appears to benefit the average to above average student and seems to be most effective when participation in the group discussions is active and is evenly distributed among students (Lindblom-Ylanne et al., 2003). However, Benckert and Pettersson (2008) report that the benefit is not as evident for students who have too little knowledge compared to others in the group, or when group dynamics are poor, or when student motivation is low (Dolmans et al., 2003).

Evaluation of the MIG Methodology

In this section, I present the findings of three studies that were conducted to evaluate the dynamics operating in MIG sessions and how these impacted student learning. The data used for the studies derived from two student surveys and a controlled experiment.

Study 1: The Students’ Experiences of MIGs:

A Content Analysis of Survey Returns

This qualitative study involved a thematic content analysis (Krippendorf, 1980) of student returns from two questionnaires (one in 2007 and one in 2008) that probed the students’ experiences of the MIG sessions. To minimize the limitations of class surveys as a data gathering methodology, the questionnaire posed primarily open-ended questions that invited the student to respond in a few sentences or a short paragraph. Restricted response questions were used sparingly and only when very specific information was sought such as recommendations about the frequency of MIG sessions. Table 1 summarizes the essential content of the student responses in 2007. The findings of the content analysis of the survey returns are discussed as follows.
Table 1. Classification of the Content of the Student Responses

<table>
<thead>
<tr>
<th>Reactions to MIG sessions</th>
<th>Comments about conceptual growth and development</th>
<th>Perceptions about learning benefits and outcomes from MIG sessions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactions to MIGs as an educational innovation</td>
<td>MIGs promoted concept formation and understanding</td>
<td>Perceptions about the educational outcomes of MIGs</td>
</tr>
<tr>
<td>Affective reactions to MIGs</td>
<td>MIGs developed thinking and problem-solving skills</td>
<td>Perceptions about how MIGs facilitated learning</td>
</tr>
<tr>
<td>i) Discomfort and disengagement</td>
<td>MIGs developed reflective practice</td>
<td>1) Broadens perspective</td>
</tr>
<tr>
<td>ii) Positive affective reactions</td>
<td>Skills gained through MIGs transferred to other subjects</td>
<td>2) Perspective broadened by peer contributions</td>
</tr>
<tr>
<td>Reactions related to students’ language constraints</td>
<td></td>
<td>3) Exposes misconceptions</td>
</tr>
<tr>
<td>i) They caused difficulties for participants in MIG sessions</td>
<td></td>
<td>4) Forces concentration</td>
</tr>
<tr>
<td>ii) MIGs facilitated language attainment</td>
<td></td>
<td>5) Provides individual attention</td>
</tr>
<tr>
<td>Reactions related to students’ constraints in technical discourse</td>
<td></td>
<td>6) Forces self-explanation</td>
</tr>
<tr>
<td>i) They caused difficulties for participants in MIG sessions</td>
<td>Comments about participating in MIGs compared to observing in MIGs</td>
<td>Perceptions about personal gains</td>
</tr>
<tr>
<td>ii) MIGs facilitated discourse attainment</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Student reactions to the MIG sessions

Reactions to MIGs as an educational innovation. Most students indicated positive reactions through statements such as ‘[MIG sessions were] helpful’, ‘must be continued’, ‘not enough of them’. The language here is clearly that of endorsement and appreciation of the MIG format. A minority indicated ambivalent or negative reactions expressed in terms such as ‘not sure how it works’ or ‘a waste of a tut period’ and ‘exposes how stupid you are’.

Affective reactions to MIG sessions. Negative affective responses were reported as discomfort caused by the MIG sessions and were associated with some degree of disengagement at a personal level. The language of the students here is typified by phrases such as ‘do not like them’, ‘scared’, ‘nervous’, ‘exposes how stupid you are’, and ‘don’t have the confidence – was afraid’. In contrast, a substantial number of students clearly found the MIG sessions to be a positive affective experience making statements such as ‘enjoyed them’, ‘was cool and fun’. Some statements conveyed a mixed reaction such as ‘started out disliking it ended up liking it’, and ‘only observing was comfortable’.

Language-related reactions. Some student reported difficulties derived from having English as a second language. Examples include: ‘difficult to explain myself’, ‘difficulty to put thoughts into words’, and ‘get stuck when trying to explain problems’. However, many students indicated the language experience in the interactional format of the MIG sessions had been a rewarding and enriching one and had facilitated language attainment: statements included ‘practice talking in English’, ‘developed my vocabulary’, ‘learn how to pronounce words’.

Discourse-related reactions. Here reactions related to difficulty with technical language and discourse such as ‘my vocabulary is pathetic’, ‘pronunciation of words is pathetic’. Some
students indicated that the MIG sessions had been helpful in addressing such difficulties: they ‘give me the language’ or ‘get me to use the correct terms’.

**Student experiences relating to conceptual growth and development**

*MIGs promoted concept formation and understanding*. Statements exemplifying this include ‘understand concepts at a deeper level’, ‘correct misconceptions’, ‘fill gaps’. This is a dominant theme in the returns and gives much credence to the endorsement given to the MIG methodology by the majority of the students.

*MIGs developed thinking and problem solving skills*. Examples of statements in this category are ‘can now think more deeply’, ‘thinking through helps with problems’, ‘I now give precise explanations’.

*MIGs developed reflective practice and skills gained through MIGs transferred to other subjects*. There were only a few statements in these two categories. Some indicated that MIG sessions had made students realize the importance of reflection in their thinking and studying: you ‘realize that you don’t understand when you thought you did’; ‘I [now] know what type of questions to ask when studying’. Other statements indicated that benefits gained through MIG sessions were beginning to work across the curriculum into other subjects: ‘can understand concept[s] in other subjects’, ‘have made me study better and I’ve applied it in my other courses’, and ‘my grasping of important concepts has improved not only in [the engineering course] but in other subjects as well.’

**Student perceptions about learning benefits**

These looked beyond conceptual growth – the focus of the previous category – and focused on learning benefits perceived to result from attending MIG sessions and on the perceived educational processes leading to these benefits.

*Perceptions about the educational outcomes of MIGs*: These included ‘promote group skills’, ‘reinforce what is taught in class’, ‘promote peer learning’, ‘fill gaps’.

*Perceptions about how MIGs facilitated learning*: Several returns included statements about specific features of the MIG sessions that respondents had noted as facilitating learning. Six features were reported.

- **Broadens perspective**. Statements illustrating this are: ‘fuller explanations’, ‘fills gaps’ and ‘look at concepts from different perspectives’.
- **Perspective broadened by peer contributions**. Statements here were similar to those in the previous category but the ‘broadening of perspective’ was directly linked to hearing what peers or the mediator said in the sessions. Examples are ‘seeing how the mistakes one’s fellow students make are rectified which are sometimes the same mistakes I make’; ‘get to know how other students think and how they develop a way to solve a given problem’; ‘see how others answer questions’; ‘allows you to share ideas and confirm with everybody else’.
- **Exposes misconceptions**. Examples of this include: ‘exposes superficial understanding’, ‘helps see ... where you have misconceptions’.
- **Forces concentration**. Here students noted how MIG sessions asked ‘hard questions’ and ‘forced you to think’ and to ‘think for ... yourself’.
- **Provides individual attention**. Here students noted, for example, that a MIG session ‘helped understanding ... because it got to the root of our problems individually’.
Promotes learning through self-explanation. Here the act of explanation was noted as helping to promote learning: ‘I found that I didn't clearly understand until asked to explain’; ‘when we are doing the discussion we are really forced to think’.

Perceptions about personal gains: The overwhelming majority of comments in this category were very positive and constituted high endorsement of the MIG sessions: ‘my marks have improved’, ‘coped better’, ‘I have more in depth understanding’, ‘[I] process questions more quickly’, ‘find tut questions more easy’, ‘[I] work more accurately’, ‘improved the way I study’. A handful of students indicated ambivalence about the benefits of the MIG sessions with comments such as ‘[benefits attained were] not dramatic’, and ‘can’t say much’.

Conclusions from Study 1

Three conclusions from this study stand out. The first is that the students described a number of educational dynamics that theory suggests should be expected in the kind of learning environment which the MIG format seeks to provide. The students noted processes which, according to Vygotsky, should be evident when a ‘more competent other’ mediates learning: expanding the awareness of the learner, concentrating attention, exposing and correcting misconceptions, and interacting with the learner to stretch the range of his/her learning. Students also noted mechanisms which theory and research suggest should occur in peer mediation and self mediation: ‘gap filling’, the self-explanation effect, mutual adjustment of perceptions, exposure of misconceptions, and peer contributions facilitating progress in learning. What is particularly interesting about these findings is not just that the MIG format seemed successful in facilitating effective educational dynamics but that these dynamics were observed by first year students who were unversed in educational theory and uninstructed about the kind of educational dynamics to be expected in mediated group discussions.

The second conclusion which stands out is the extent to which students reported individual change as a result of having attended the MIG sessions. Most students reported changing in ways intended by the MIG design – their conceptual understanding improved. However, change was also reported in regard to cognitive and reflective skills, improvements in technical discourse and language usage, and changes that helped students to cope better or to work more quickly and effectively.

The third conclusion from the study is that the interactional nature of the MIG sessions engendered some strong affective reactions among the students. In some cases, these were positive and motivational. In other cases, they were not: the MIG context placed language, discourse and affective demands on the students and difficulties arose when these demands were too big a stretch. To some degree and for some students, such interactional difficulties appear to have diminished the educational impact of the MIG sessions. The extent of these negative reactions is one of the topics taken up in the next study.

Study 2: The Distribution of Student Experiences of MIG Sessions

The content analysis in the previous study established a range of categories of student reactions to the MIG sessions. This study was more quantitative in nature and investigated how the student reactions were distributed among those categories. The coded survey returns were re-examined and a simple head count made of the number of students who had made statements falling in each category. During the analysis it became evident that the number of categories could be usefully reduced to five essentially different types of reaction to the MIG sessions. These five ‘reaction types’ are listed and described in Table 2 along with the
proportion of students who reported each type of reaction. The fourth and fifth columns give the distribution of students whose reactions fell in more than one category.

A particular concern in this study was the reactions of students who had reported not having had a positive experience. To gain further insight on this, an analysis was undertaken of responses to two restricted-answer questions in the surveys. The rationale behind the first question – “How frequently would you like to attend MIG sessions?” – was to get an indirect indication of the extent to which the students rated the MIG sessions positively. It would be expected that students who appreciated or saw value in the MIGs would recommend a high frequency, while those who did not appreciate them would not want to attend them at all or very infrequently. The results are summarized in Table 3.

**Table 2. Distribution of Student Perceptions and Experiences of MIGs**

<table>
<thead>
<tr>
<th>Type of Reaction</th>
<th>Perception or Experience of the Student</th>
<th>Proportion of Students % (Number)</th>
<th>2008 Survey (118 returns)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2007 Survey (52 returns)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2007 Students with overlapping reactions ... ‗Positive experience‘*</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>... ‗Experience not positive‘*</td>
<td></td>
</tr>
<tr>
<td>Positive experience</td>
<td>Student reported positive personal change plus positive educational processes in MIGs and/or positive educational outcomes from them.</td>
<td>92% (48 students)</td>
<td>87% (103 students)</td>
</tr>
<tr>
<td>Experience not positive</td>
<td>Student was ambivalent or negative about MIGs and was negative or ambivalent about personal change resulting from attending them.</td>
<td>8% (4 students)</td>
<td>1% (1 student)</td>
</tr>
<tr>
<td>Outcomes dubious</td>
<td>Student was ambivalent or negative about outcomes from MIGs and/or whether the educational processes in MIGs were beneficial.</td>
<td>12% (6 students)</td>
<td>10 % (5 students)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2% (1 student)</td>
<td>7% (8 students)</td>
</tr>
<tr>
<td>Discourse difficulties</td>
<td>Student experienced difficulties in MIGs because of language or discourse constraints.</td>
<td>13% (7 students)</td>
<td>13 % (7 students)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0%</td>
<td>0%</td>
</tr>
<tr>
<td>Affective difficulties</td>
<td>Student experienced affective difficulties in MIGs with some discomfort in the sessions.</td>
<td>35% (18 students)</td>
<td>27% (14 student)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>8% (4 student)</td>
<td>8% (4 student)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3%</td>
<td>3%</td>
</tr>
</tbody>
</table>

* as defined in the second column

1 Seven of the 118 returns were incomplete.

The second restricted answer question probed directly the students’ affective reactions to the MIGs and how this impacted their motivation to participate in them. The question was preceded by a preamble that summarized the kind of affective pressure participants in a MIG session might feel and possible reasons for them. Students were then asked to indicate – by selecting from a list of options – the extent to which they had been or thought they would be comfortable to be a participant in a MIG session given those pressures. The options are indicated in Table 3 along with the results.
Conclusions from Study 2

It is quite clear from the 2007 and 2008 surveys that the reactions of most students to the MIG sessions were overwhelmingly positive. Table 2 shows that 92% of the students surveyed in 2007 had had a ‘positive experience’ and justified the positive rating they gave MIGs on the basis of a variety of personal learning gains that the students perceived were forthcoming. In 2008, 87% reported a positive experience. Table 3 conveys a similar degree of endorsement. In the first place, 77% of students stated they would like to attend MIG sessions weekly or as often as possible. Secondly, even students who had been uncomfortable as a participant (or felt they might be) saw value in the sessions and were willing to attend them.

Table 3. Responses to Restricted Answer Questions in the 2007 Survey

<table>
<thead>
<tr>
<th>Question</th>
<th>Number of Responses</th>
<th>Response Categories</th>
</tr>
</thead>
<tbody>
<tr>
<td>How frequently would you like to attend MIG sessions? (52 responses)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 (4%)</td>
<td>Never</td>
<td></td>
</tr>
<tr>
<td>5 (10%)</td>
<td>Once per quarter</td>
<td></td>
</tr>
<tr>
<td>4 (8%)</td>
<td>Once per month</td>
<td></td>
</tr>
<tr>
<td>16 (31%)</td>
<td>Once per week</td>
<td></td>
</tr>
<tr>
<td>24 (46%)</td>
<td>As often as possible.</td>
<td></td>
</tr>
<tr>
<td>1 (2%)</td>
<td>(Once per week or as often as possible = 77%)</td>
<td></td>
</tr>
<tr>
<td>To what extent were you or would you be comfortable to be a participant in a MIG session? (46 responses)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24 (52%)</td>
<td>No problem</td>
<td></td>
</tr>
<tr>
<td>17 (37%)</td>
<td>Was/would be a bit uncomfortable but that’s OK</td>
<td></td>
</tr>
<tr>
<td>3 (7%)</td>
<td>(No problem or a bit uncomfortable but that’s OK = 89%)</td>
<td></td>
</tr>
<tr>
<td>1 (2%)</td>
<td>Was/would be uncomfortable quite a lot but that’s OK</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>Was/would be uncomfortable – not sure I want to do it</td>
<td></td>
</tr>
<tr>
<td>1 (2%)</td>
<td>Definitely uncomfortable and don’t want to do it</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(I have another reaction which is …</td>
<td></td>
</tr>
</tbody>
</table>

In some cases, the positive reactions to MIG sessions were very enthusiastic, as the following quotations indicate.

“I always had a shallow understanding of concepts and relied on text books and my study group for assistance. But the sessions have been incredibly helpful in such an extent that I [now] always ask myself questions whenever studying a concept.”

“These are the most help and efficient exercise in all my courses. They should be implemented in the other courses.”

“Very, very, very, very helpful! Most of the deep understanding of the concepts comes from the [MIGs].

“This for me is the cream for all my problem-solving and understanding place of the week.”

“This is the best thing that helps me with [the course]. I don’t think I was going [sic] to manage to pass [the course] without [these] groups.”

While a positive experience of a methodology is not, on its own, sufficient reason for recommending that methodology, it is not inconsequential. Students are likely to gain more from an intervention if they appreciate it and value what it appears to offer them.

As Table 2 indicates, there were four types of reactions to MIGs that were other than positive. The first of these was a generally negative reaction: students were ambivalent or negative.
about the MIG sessions and the outcomes derived from them. In 2007, 8% of students reported this reaction but in 2008 only 1% did so.

With regard to the other three types of non-positive reaction – outcomes dubious, discourse difficulties, and affective difficulties – the fourth and fifth columns in Table 2 indicate the extent to which these reactions did or did not impact negatively on the benefits students saw or experienced in the MIG sessions. The table shows that all students who experienced ‘discourse difficulties’ also reported a positive experience. It also indicates that all but one of the students who seemed to be dubious about outcomes did seem to derive some benefit from the MIG sessions. A similar conclusion seems to apply to students who experienced affective difficulties in the MIG sessions: three quarters of them also reported positive outcomes and/or positive personal change and only a quarter reported a negative reaction to MIG sessions.

These results are an important complement to the earlier findings that an overwhelming majority of students endorsed the MIG methodology. It indicates that even when students experienced affective and language-related difficulties in MIG sessions most also derived discernible benefit from attending them: in most cases, affective difficulties did not appear to impair the motivation of student to attend MIGs.

**Study 3: A Quantitative Evaluation of the Impact of MIGs on Student Learning: A Controlled Experiment**

This study addressed the question of the extent to which learning outcomes are different when the teaching and learning environment includes MIG sessions. The study involved a tightly controlled experiment that compared the performance of an experimental group against that of a control group. It was possible to set up such an experiment when the MIG format was still ‘on trial’ in 2007 because not all students participated in MIG groups each week. The experimental group consisted of students who had participated in a MIG session on a ‘difficult concept’. The control group consisted of those who had not attended any MIG session on that topic. Further, the experiment was very tight in that the exposure to the topic for the experimental and control groups was the same in all respects except for a half hour session when the experimental group participated in a MIG discussion on the topic while the control group continued working on the tutorial devoted to the topic in the normal tutorial session. To maintain uniformity of mediation, I mediated all the MIG sessions involved in the experiment.

An unplanned twist in the circumstances of the study increased the force of the comparison between the two groups. This twist was a consequence of the tendency for MIG groups to self select during the trial period. As shown in Table 4, the students in the experimental group turned out to be academically weaker than those in the control group. The relative ‘academic strength’ of the two groups was gauged on the basis of psychometric data that had been taken at the beginning of 2007, specifically their scores from the Ravens Advanced Progressive Matrices (RAPM) (Raven et al., 1998). The category of ‘strong academic level’ in Table 4 corresponds to superior intellectual capability: students who should graduate in regulation time possibly with distinction. At the other end of the scale, the category ‘weak academic level’ is associated with RAPM scores that fall below 22 which corresponds roughly to a fairly well recognized cut-off level for acceptance into engineering degrees (Skuy et al., 2002). As the table shows, the difference in academic strength of the two groups was stark: 11% of the experimental group was ‘academically strong’ and 39% ‘academically weak’ as compared to the control group where 37% were ‘academically strong’ and only 16% ‘academically weak’. 
The controlled experiment was conducted during the week in which a difficult and counter-intuitive concept was first taught. The extent of student learning was gauged by whether or not the students applied the concept correctly in a scheduled term test three weeks after the topic was first introduced. The results are presented in Table 4.

Table 4. Indications of Student Mastery of the Troublesome Concept  
(Statistical measures: p = 0.203, n = 69)

<table>
<thead>
<tr>
<th>Level of Academic Ability*</th>
<th>Number of students</th>
<th>Applied the concept correctly?</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Strong</td>
<td>Average</td>
</tr>
<tr>
<td>Experimental Group</td>
<td>11%</td>
<td>50%</td>
</tr>
<tr>
<td>Control Group</td>
<td>37%</td>
<td>47%</td>
</tr>
</tbody>
</table>

* Categories of academic ability were based on the students’ scores from the Ravens Advanced Progressive Matrices (RAPM) (Raven et al., 1998) as follows:-
Strong: RAPM scores between 28-33; Average: RAPM scores between 22-27; Weak: RAPM scores <22.

The proportion of students who applied the concept correctly was 89% for the experimental group and 71% for the control group – a difference of 18%. A sensitivity test found that this difference would need to be about 25% for it to be statistically significant (p = 0.05).

Conclusions from Study 3
Despite the lack of statistical confirmation, a very clear trend is evident from this study: an experimental group that was academically much weaker than the control group outperformed that control group by a dramatic margin – 18%. This provides strong evidence that the MIG sessions had achieved a marked improvement in the conceptual learning of the students involved. That they had achieved this improvement by means of just one 30 to 40 minute MIG session is noteworthy.

Two qualifications apply to the findings just presented. Firstly, the small number of students in the controlled experiment precluded a meaningful statistical examination of the effect of the relative academic strengths of the two groups. Secondly, the improvement in academic performance at the heart of the analysis applied to only one topic among many: this singular focus of the controlled experiment enabled a very tight assessment of student learning, but it left unanswered the larger question of how MIG sessions affected the overall pass rate and academic performance of the students. A meaningful longitudinal study to investigate this was not possible because the development of the MIG methodology coincided with a 150% increase in student numbers as well as a significant change in the educational background of the incoming cohorts.

Conclusions and Recommendations
The paper has described an innovative methodology which enables students in a large class to regularly participate in discursive interactions in which the effective student/staff ratio is 4:1. The paper evaluates the effectiveness of that arrangement. The findings are in two parts. The first relates to affective and language-related difficulties which students may encounter in MIG sessions. The study has shown that such difficulties affected only a minority of students and that the extent of these difficulties and of their impact can be very significantly reduced: students barely mentioned them in the 2008 survey.
The second set of findings concern the efficacy of the format. The study showed that the educational processes in the MIG sessions were very much in line with those which theory and research indicate should be expected. The level of agreement between theory and what students reported seeing in the MIG sessions has two significant implications.

The first is that it provides evidence of the reliability of the findings of the survey study. That 1st year engineering students unversed and uninstructed in the educational processes associated with mediated interactions have reported observing a range of features that line up well with the literature is noteworthy. It gives credence to the claim that what they reported was actually what they had seen and experienced: it gave ‘observational validity’ to the findings. The findings also had ‘content validity’ in that they faithfully reflected the content of what students had written in the returns. This is claimed on the grounds that the study adhered to a well-established research methodology namely content analysis.

The second implication of the agreement between theory and what students reported is that it indicates that the MIG methodology can and did create a learning environment in which educational processes potentially beneficial to student learning were operating.

With regard to whether these processes did achieve the learning benefits which theory and research suggest should be forthcoming, both the qualitative and quantitative studies yielded positive findings. In the first place, content analysis showed that the educational processes operating in the MIG sessions seem to have been powerful in changing students: individual change was a dominant theme in what the students communicated. About 90% of those surveyed in 2007 reported personal change that ranged from enhanced conceptualization to cognitive and meta-cognitive development, to improvements in language usage, technical discourse and learning practices. Linked to these changes were reports of changes in academic performance: improved speed, accuracy and execution in problem solving, coping better, and, in some cases, improved grades. In 2008, a similar proportion of students reported personal changes of these kinds. While no claim is made that every student changed in all the ways listed, it is significant that almost all of these students reported some change – especially improved conceptual understanding – and most reported beneficial change in more than one area.

Additional interesting conclusions from the evaluation study relate to the type and range of the changes reported. The objective of the MIG sessions was to enhance conceptual mastery by having students articulate and discuss key conceptual issues in the course content. However, the learning environment set up to facilitate such articulation seemed to have had a much more multidimensional impact on learning. This is reminiscent of Feuerstein’s point that a deeper level transformation in cognitive functioning can occur when a learner wrestles with the cognitive particularities of specific situations in a strongly mediated environment (Feuerstein, 1979; Feuerstein & Feuerstein, 1991). It can be concluded from these observations that the MIG sessions in 2007 and 2008 implemented an interactional learning environment which generated multiple learning impacts leading to a rich variety of benefits for student learning.

The quantitative study provided some confirmation of this positive result. It showed that participation in a half hour MIG session resulted in an experimental group of academically weaker students outperforming by a margin of 18% a control group of academically stronger students who had not participated in the relevant MIG sessions. When all the findings are combined – the 18% margin, the fact that the experimental group were academically weaker, the demonstration that educationally effective dynamics were operating and that students reported real and multiple learning benefits – the indications are very positive and provide
very strong evidence that the MIG sessions did indeed lead to a marked improvement in the performance of the students in the experimental group and that the MIG methodology is able to bring about a very real improvement in student learning.

References


Acknowledgments

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The Discursive Construction of Teaching and Learning in an Academic Literacy Course for Engineering

Annah Vimbai Bengesai
Academic Support and Advancement Programme, Faculty of Engineering, University of KwaZulu-Natal, South Africa.
bengesai@ukzn.ac.za

This paper examines an academic literacy course within an engineering faculty. The course in question (Technical Communication for Engineers) was introduced in 2008, under the auspices of an academic development programme in the faculty as the key ‘support’ service for engineering students; therefore, it is important to evaluate its impact. The rationale for such a course is to remove barriers to epistemological access to the engineering discourse; cast in this way, the course is framed within a social justice framework.

Scholars such as (Street and Lefstein, 2008; Barton, 2007; Ivanic 2004; Kern, 2000; Gee, 1996) have raised our awareness of the competing definitions of literacy. This suggests that there are different understandings of what constitutes literacy. These competing perspectives of literacy also indicate that questions about academic literacy are related to questions about identity. In particular, they reveal how social and academic relationships between students and their educators shape how academic literacy is defined and in turn define/represent students. If this is the case, then it would be fair to say that whatever representations of literacy emerging in the teaching and learning context, they are a reflection of practitioners’ ontological frameworks. Taking this position therefore, that academic literacy is discursively constructed, I seek to explore the ‘contact zone’ between students and their educators in the Technical Communication for Engineering course. My main aim is to examine how these different actors (students and their educators) in the teaching and learning context enact the discursive spaces they find themselves in. A specific question to be addressed is: what discourses frame the teaching and learning of academic literacy in the Technical Communication for Engineering course? Hence, the framework that I have chosen allows for an examination of institutional practices of teaching and learning. To do this, I have employed a multidisciplinary approach drawn from applied linguistics, sociology and philosophy. Consequently, I rely largely on the New Literacy Studies (NLS) as well as Bhaskar’s Critical Realism.

The NLS’ approach to the understanding of literacy emanates from the premise that literacy is a social practice (Street, 2003; Barton and Hamilton, 2000; Gee, 1996). Therefore, there are many literacies. This conception helps practitioners to move away from seeing literacy as a de-contextualised skill or a metaphor for competence (Street, 2003). The NLS scholar, Gee has also made a remarkable distinction between the small letter ‘discourse’ and the capital letter Discourse’ (Gee, 1996). The small letter discourse Gee, maintains basically refers to language in use, whereas the capital letter Discourse, is a Foucauldian construct which refers to language as a social practice. For this reason, Gee sees academic literacy as a Discourse. If literacy is a Discourse, and identity is discursive, then I am in good company relying on the NLS for this study. This is because this framework helps me understand how representations

1 I use the term ‘support’ with a degree of restraint in this paper. This is because the dominant understandings of academic ‘support’ have tended to take on a ‘deficit’ approach to learning.
(identities) of students are mediated through this Discourse, the Technical Communication Course.

Reflecting on Gee’s distinction between the small letter discourse, and capital Discourse I will therefore examine the teaching and learning context framing the Technical Communication course. As a result of such a focus, I first explore the small letter discourse, that is, the language that is used to represent academic literacy and consequently students. From these, I then focus on the capital letter Discourse, in an attempt to bring to the fore the socio-cultural representations that these discourses bring out and the ways in which they produce Discourses that serve to maintain hegemony in academic practice. Gee, as a linguist, has also suggested the use of discourse analysis. To do this I will be guided by the ontological meta-theory of critical realism, in methodology as well as in analysis. I will try to uncover the ‘generative mechanisms’ that lead to the development and perpetuation of such Discourses.

Critical Realism draws from the understanding that reality is multi-dimensional and stratified (Bhaskar, 1978). By doing this, Critical Realism illuminates reality, given it helps the researcher take into account heteroglossia (Bakhtin, 1981) in which multiple voices are seen as fundamental in any discourse. Hence, in the context of the Technical Communication course as a Discourse, I anticipate to find different conceptualisations of the notion of academic literacy.

Critical Realism’s position on the relationship between knowledge and language is also of essence. Critical Realists hold that dominant discourses in society influence people’s perceptions as well actions (Trowler, 2001) and in turn help to define (represent) others. Hence, reality is not independent of language and discourse; it is discursively constructed (Gee, 1996). If reality is discursively constructed, then it is multi-faceted. If that is the case, then whose reality is privileged in the academy; what kind of representations does this kind of reality give rise to? This position is relevant to this study because it helps illuminate the complexity and differential practice which leads to the development of Discourses in higher education.

Discussion

At the time writing this paper, I am still engaged in the process of data collection. Hence, this paper presents work in progress. Nonetheless, what is clear is that there are two discourses emerging from the Technical Communication for Engineering module. Following Boughey (2002) I have termed one of these discourses the ‘second language’ discourse. It seems that great import is put on ‘good command of English’ at the expense of Discourse. Hence, whilst students’ problems with language are made visible, there is no attempt to problematise the Discourse of technical report writing and the pedagogic practice. Although this discourse seems to be embraced by both students and academics, there are also signs of resistance on the part of students. Also emerging from the Technical Communication for Engineering class is an exclusion discourse. On the one hand, students see the module as a ‘language support programme’ and something that they should not be doing as engineering students. On the other hand, the tutors, who teach the module feel excluded in the sense that they cannot get students to the ‘desired levels’ of competence. Thus, they express frustration at the situation and feel excluded from the task they are engaged to do. Given this is work in progress, more findings will be reported at the conference.

References


Establishing a Culture of Research in an Engineering Faculty at a South African University of Technology

Wolf Bernhardt¹, Theo Andrew² and Mark Walker³

Faculty of Engineering and the Built Environment, Durban University of Technology, Durban, South Africa

¹herbert@dut.ac.za, ²tandrew@dut.ac.za³, walker@dut.ac.za

Research has not been a core academic activity for the former Technikons in South Africa despite it being a priority in their mission. With the advent of the University of Technology (UoT) replacing former Technikons and in some cases being ‘merged’ into a Comprehensive University, both national imperatives and the university community expectations necessitate a vibrant research culture at UoTs. The number of incentives such as Research Development Grants, Study Leave, Agency Funding and the “carrot and the stick” within an institution do not seem to produce the desired amount of sustainable productive research at most UOTs. It is the contention of the authors, based on experiential evidence, that a generalised management approach to research development, which includes elements of strategy such as target setting and unrealistic timelines, transferring responsibility to newly recruited scholars, and bureaucratising research, has had insignificant impact and will continue to do so.

We propose an approach that seeks to transform a defined organisation such as an academic department or faculty towards a scholarship culture through an intervention process that is underpinned by an established methodological framework that promotes multiple loop learning, empowerment and emancipation amongst individuals in the group.

This paper discusses an intervention in the Faculty of Engineering and the Built Environment (FEBE) at the Durban University of Technology (DUT) that seeks to establish the necessary conditions for a productive and sustainable research culture within the Faculty. While there are a number of successful and productive researchers in the Faculty, this is insufficient for a university.

Based on our experience and observation over the years we have decided to deal with the problem situation from the inside of the Faculty unit taking ownership of the intervention. The principles laid down were:

- The intervention has to be transformative in nature; first for the individual and then for the organization
- The actors in the intervention must include the internal, and also to some extent, external agents of change
- The intervention must seek to mitigate power and bureaucracy, promoting emancipation and empowerment
- The intervention must be informed by a rigorous methodological approach that enables the actors to first make sense of the current reality. It will need to be able to deal with the inherent complexity of the intervention
- The nature of the intervention itself must be knowledge generating so that there is continuous learning as the improvement takes place
- The intervention must be systemic in nature
The approach adopted in establishing a “culture” of research is that of action research. This is done to promote involvement, participation and mutual encouragement. It is not only aimed to increase the number of staff members registering for post-graduate degrees, but to create an enabling environment in which staff start talking about specific problems and ideas in their research with peers. Furthermore, it was seen important to establish groups or “cells”, led by experienced facilitators, where a certain degree of similarity exists amongst the research interests of the members, so that there can be non-threatening evaluation of sections of individuals’ work and where people establish relationships which are stimulating and mutually supportive. This approach also aims to help those staff members who feel they do not possess the skills to do meaningful research to overcome these feelings of inferiority and helplessness, and to initiate them into the world where a continual quest for useful knowledge becomes a way of life.

Soft System Methodology (Checkland, 1981) was used as the main guiding methodology for the intervention although it was not necessary to make the tenets of the methodology explicit to those concerned. The paper will discuss briefly the essential features of the methodology, the interrelated problems (mess) generated by SSM. The first stage conceptual models that are emerging and the human activity systems that are put in place to bring about the transformation are presented.

As this is a longitudinal study it will not be possible to discuss a complete set of observations and results. However, reflections on the intervention thus far and the knowledge generated will be shared.

References

Engineering Student Retention and Success: An Investigation into Contributing Factors

Frikkie Conradie\(^1\) and Hannes du Toit\(^2\)

\(^1\)School for Chemical and Minerals Engineering, North West University, South Africa; \(^2\)School for Chemical and Minerals Engineering, North West University, South Africa

1frikki.conradie@nwu.ac.za, 2hannes.dutoit@nwu.ac.za

A variety of approaches and models to student retention and success was proposed by Christie (2004), Willcoxson (2011), Veenstra (2009), Sandler (2000) and Thomas (2002). The diverse series of influencing factors included pre-university academic performance, first year performance, the role of the institution, personality and environment of the student, course choice and clarity of career, student perception and commitment of and to the institution, student social support network, finance, employment, study habits and perceived stress to name but a few.

To explore and to try and address some of these factors a module in the engineering curriculum called Professional Practice (PP1) was introduced. In PP1 the student is exposed to a simulated environment that aims to enlighten the student’s perspective on the reality of engineering. In this module the student’s study habits, commitment to career and educational goals, confidence in quantitative skills and to some extent the social engagement is addressed with the formation of groups with separate and completely diverse projects.

Each group is assigned to a real life client and each project has a real problem associated with it. Each project has financial and time limitations. In the process of solving the client’s problem the student is tasked with navigating interpersonal communication in group context and with cultural differences. The students should keep track of detailed configuration management including meeting agendas, action lists, gantt charts and meeting minutes. This simulated environment connects the real life application of project management and systems engineering on a first year introductory level and it brought about the integration of student engagement with an engineering career. This process encourages the student to explore engineering at its heart and exposes the student to the everyday inner workings of a reality based approach to engineering. In the light of this change in curriculum and perspective an investigation was conducted to ascertain the success that this practical application could have on student retention and success.

Combining data from a survey questionnaire, institutional records as well as student interviews some general conclusions could be made. Students generally have no prior knowledge of the engineering community of practice. The experience in this module developed an engineering culture that helped the students form part of a group that aided there engineering development. Students find in the tutor system (inherent in the approach of PP1) a figure that helps mitigate the gap between first year student, senior student and educator. Positive responses obtained from students verify this:

“PP1 made me feel like I am part of a group that I could trust and rely on for any engineering questions that I had.”

“I found someone to look up to, my tutor, and someone to ask questions. All my questions.”

“Completing my vacation work at SASOL I realised that the environment I am exposed to in PP1 helped me with my transition of student thinking to engineer thinking.”
Some negative feedback from students confirmed that the engineering profession was not what they had envisaged. Some noted that PP1 was the very reason they changed career choice while others found group work upsetting and frustrating.

“I was shocked to see that engineering was not at all what I had in mind, that if why I am perusing a career in finance instead”

“The workload is too much”

“The influence of team evaluation on my grade is unnerving and unfair, and group communication was absent to a great extent”

The introduction of PP1 into the curriculum was to expose students to a real life authentic engineering environment that will help them to find their way in the community of engineering at large. It helps the student to make the transitions from student to engineering thinking and helps develop an identity for engineering. This was achieved to some extent in the first year already with the help of PP1. At this stage we foresee that we could utter the words of Lindsay (Lindsay et al:2008) “To an extent this unit was too successful”, in a few years time.

References

Designing an Integrated Higher Education Programme for Engineering Surveying in South Africa

Angus Forbes\textsuperscript{1} and Jacobus Landman\textsuperscript{2}

\textsuperscript{1}School of Civil Engineering, Surveying and Construction, University of KwaZulu-Natal, South Africa; \textsuperscript{2}Department of Civil Engineering and Surveying, Mangosuthu University of Technology, South Africa

\textsuperscript{1}forbesam@ukzn.ac.za, \textsuperscript{2}landman@mut.ac.za

The recent introduction of the Higher Education Framework (HEQF) has created the need to review the engineering surveying curricula in South Africa. Higher Education has two main providers: Traditional universities, Cape Town (UCT) and KwaZulu-Natal (UKZN), offering a BSc, MSc and PhD Degrees in Land Surveying, and the Universities of Technology, Cape Peninsula (CPUT), Durban (DUT), Tshwane (TUT) and Mangosuthu (MUT) offering Diplomas, B.Tech, M.Tech and D.Tech Degrees in Surveying. In addition; the South African Qualifications Authority (SAQA) accredited providers may offer SAQA accredited unit standards and qualifications. The Chief Directorate: National Geospatial Information (CD:NGI) offers the Geomatics Officer course. The courses offered vary in duration, objective, level, practical application and exit level outcomes.

Due to the new HEQF, an opportunity has now presented itself for the re-design of learning programmes to be done in such a way that an integrated programme for engineering surveying becomes a reality. However, a change in the design of a curriculum to promote integration must be done without sacrificing the quality of the current courses. Curriculum development, core surveying engineering knowledge, learning and teaching methods and technologies, educational management and marketing, continuing professional development, and networking in education and training are all factors that could contribute towards a viable educational dispensation for engineering surveying.

Advantages of integration

An integrated approach to designing Engineering Surveying curricula, in particularly the first degree qualifications, will have an impact on the duration of the qualifications, should a learner wish to transfer between the institutions. Transferring students presently obtain very little credit because of the different structures of the various qualifications. It is therefore important to establish how different institutions offering engineering surveying relate to each other, before any adjustments towards an integrated system could be made.

Academic requirements for the appointment of academic staff at higher education institutions are very high. For a lecturing position the minimum requirement is a M.Sc. and registration for a Ph.D. As a result the filling of vacant positions in the various survey departments is difficult. An integrated education system could relieve the staff shortage as courses in Engineering Surveying could be shared and staff lecture at multiple institutions.

Survey equipment is very expensive and the cost to fully equip a department runs into millions of rands. The maintenance and continuous upgrading of equipment is a regular annual cost. Such costs could be kept to a minimum by the sharing of equipment by survey departments that are situated in the same municipal area.
South Africa is fortunate that almost all (TUT being the exception) the institutions are based in Cape Town or Durban so the integration advantages described above should be feasible.

**Entry level requirements**

The existing minimum entry level varies between institutions.

Both UKZN and UCT require applicants to have obtained a National Senior Certificate (NSC), or equivalent, with good passes in Mathematics and Physical Science as well as a pass in English. (UCT, 75% for Mathematics, 65% for Physical Sciences; UKZN 70% in both Mathematics and Physical Science).

The Universities of Technology (UoT) require applicants to have obtained a NSC, or equivalent, with passes in Mathematics and Physical Science and a language (usually 40%) combined with a points system.

The CD:NGI requires applicants to have obtained a NSC, or equivalent, with at least 60% in Mathematics and English, and 50% in Geography.

**Registration**

Although there are several engineering surveying qualifications there is no legal necessity to be registered in order to undertake engineering surveying work.

South African Council of Professional and Technical Surveyors (PLATO), the accreditation body in terms of the Professional and Technical Surveyors Act 40/1984, register Professional Engineering Surveyor’s with a BSc Surveying degree (4 years), or a B.Tech degree.

Accreditation of institutions is undertaken by the Education Advisory Committee (EAC) of PLATO.

**The Higher Education Qualifications Framework (HEQF)**

The introduction of the HEQF has opened the door for institutions of higher learning to create an integrated education system where learners may transfer credits between institutions including surveying engineering programme. The HEQF was published by the government in 2007 and was to be implemented by 2009. It prescribes the qualifications that can be offered in future by South African higher education institutions. All new programmes that are introduced must be in terms of this structure and all existing programmes will have to be converted to one or more of these structures.

Recent attempts to implement such changes have, in some cases, met with institutional resistance.

**Core courses, Unit Standards and Industry Requirements**

The Surveying Standards Generating Body (SGB) has produced a qualification at National Qualifications Framework (NQF) level 7 which meets the PLATO requirements through Unit Standards (National Qualification: Geomatics, SAQA qualification 21851). However the qualification has not been registered and no learner has undertaken this path. Furthermore, the infrastructure required to complete the qualification does not exist. The qualifications offered by existing higher education providers are not based on unit standards.
Unit standards were developed at differing education levels (with no entry level requirements for the basic courses) and outcomes.

The SGB identified core courses required for engineering surveyors, a description of the course content, its level, outcomes and an estimate of time required.

**Exit Levels, Integration Points and Credit Transfer**

With the exception of the UCT BSc degree which allows some transfer of credit from UoTs and a reduction in the length of the degree there is no significant integration between different types of higher educational institutions.

The exit level qualifications from the various institutions are; the Geomatics Officer certificate, National Diploma: Surveying, B.Tech., B.Sc. (Survey), M. Tech., M.Sc., D. Tech. and Ph.D.

**Conclusion**

A change in the design of a curriculum to promote integration must be done without sacrificing the quality of the current courses. This paper investigates a number of possible adjustments towards an integrated curriculum, including pedagogic techniques, curriculum development, core surveying engineering knowledge, learning and teaching methods and technologies, educational management and marketing, continuing professional development, and networking in education and training.
Design of a Learner-Centred Engineering Complex

Andre Hattingh  
Faculty of Engineering, North-West University, South Africa  
agh@mweb.co.za

The Department of Higher Education (DoHE) made funding available for the development of new infrastructure at engineering faculties in order to increase the number and quality of engineering graduates. This opportunity allowed the North West University (NWU) to develop new facilities that will support new and innovative educational strategies.

The notion of “learning spaces” developed in parallel with learner centric education. Lecturing, and the customary lecturing hall, is now only one of a number of learning modalities available to the engineering educator.

The NWU used a QFD (Quality Function Deployment) approach to develop solution-free User Requirements (UR’s) for the new engineering facility. A number of interesting and novel solutions to the UR’s were incorporated in the final design.

Background

The department of Higher Education (DoHE) is investing R316 million for new infrastructure at the seven engineering faculties in South Africa. The grant gave the faculty the opportunity to design a new facility from first principles, but the very low level of funding meant that the faculty had to apply its mind to how the funding was utilised.

The faculty of engineering at NWU is currently spread over a number of buildings. The existing facilities were not originally designed for the engineering faculty, and consisted therefore of unplanned lecturing areas, scattered offices, convoluted passages and disjointed laboratories.

The grant gave the faculty the opportunity to design a new facility from first principles.

Theory

Educational facilities are changing and the most visible is the change from formal lecturing halls to learning spaces of different configurations. At least three forces drive the change: The changing profile of students, a better understanding of how learning takes place and pressure to improve efficiencies in the system.

These forces also drive innovations in engineering education. The trend seems to be from teaching to learning, and the spaces in which education takes place therefore needs to be learner centred spaces. The change is sometimes dramatic, and can be summarised as follows:

- The blurring of the distinction between lecture rooms, laboratories, workshops, and recreational areas into multifunctional learning spaces
- The total integration of space and technologies, specifically IT technologies
- The move from static, pre-allocated areas to dynamically reconfigurable spaces
- The design and use of space as a catalyst of innovation and learning
A closer linking between learning approaches and the use of space.

Learning spaces now tend to be multifunctional and stimulate interaction between people, and between people and technology. Some of the reasons will now be discussed.

Students are changing faster than institutions

The profile and preferences of students have changed during the last decade. (Brook, 2009 & Prensky 2011) Students are not energised in large lecture halls. They use technology such as text messaging, e-mail, or social media as a virtual means to continue their preference for informal, small-group discussion, in order to understand curriculum content.

Students are visually orientated, and they need networks in which they can get to know one another. They are mobile, engage in dialogue, and are highly networked. They prefer to work in groups on projects, and they seek a collaborative environment that fosters understanding and learning. The students do not prefer lecture style teaching, but prefer active learning strategies.

Learning spaces support a variety of teaching – learning approaches

The popularity of the term “learning spaces” coincided with the change in emphasis from teaching to learning. It is also a useful tool to align educators to the notion of learner-centric education. Learning spaces aims to provide a space where the mode of education can be aligned to the cognitive style of the facilitator, the learning preference of the students, the type of material, and the required outcomes. (Kolb & Kolb, 2005)

Space can be real or virtual and should be “sticky” in the sense that it enhances interaction. (HermanMiller, 2009)

Learning spaces allows better utilization of space and time

Over the lifetime of a building, the cost of the human resources using the building are much more than the cost of the furnishing, which is much more than the cost of the building. Acker & Miller (2005) therefore argue that universities should build and develop space as a response to the call for accountability, to improve long-term investment, and to commit to 24/7 learning.

Learning spaces should be student-centred rather than teacher-centred and integrate technology and space in order to meet the pedagogical and student needs. It should also be flexible, ergonomically comfortable, functional, and multi-usable. This is more an evolutionary process than a revolutionary one. (Wilson G. and Randall, 2010),

Methodology used

The NWU-planning team used the precepts of Quality Function Deployment (QFD) as a tool to identify the Voice of the Customer (VOC). The QFD process leads to solution free, expressed, assumed, and latent user requirements. A separate process is then used to identify, rank and cost solutions. The solutions are linked to clustering concepts and the budget.

The VOC captured some interesting concepts. It is noteworthy that although this was an independent process, many ideas correlate with international trends:

- Generic, multipurpose, reconfigurable spaces. This implies that the lecturing areas are flat, with removable walls and no preferred orientation.
- Breaking down of silos. The building must encourage personnel from different schools to mix, and force individuals to make contact at certain nodes.
The facility must form a hub with workshops, laboratories, lecturing areas, and offices integrated in one educational innovation system.

The whole building must be technology-, and specifically IT friendly.

The second phase of the QFD process is to link technology and implementation options to the VOC and to use an iterative process to identify the best solution.

Educational trends were investigated and taken into account: The trend towards problem and project based learning informed the design of the lecturing areas, while the trend towards interconnectivity, wireless networks and social networking defined the lay-out and use of the facility. We planned the facility to be 24/7 in use.

We took cognisance of the profile of the students of the 21st century.

We developed clustering concepts. The lay-out of the facility is based on clustering and proximity models which bridge the gap between needs and usability. This led to a number of interesting concepts. For instance, the workshops, laboratories, offices and lecturing areas are all linked in such a way that a small forklift could travel from one to the other. The proximity of the lecturing areas and the workshops means that students can experience a theoretical-practical session.

The planning team visited examples of good engineering facilities as well as bad facilities in South Africa and internationally, and noted which attributes acted upon which user requirement.

Some outcomes

The learning areas in the complex are all multifunctional and can be used for practicals, lectures, tutorials, exhibitions, examinations seminars, as a studio or workshop, for formal or informal collaboration. The areas are flat, with movable tables and chairs, and removable walls/partitions. The three large learning areas are massive, and can accommodate almost 600 students when undivided. When partitioned, each area can accommodate 150 students. All walls are covered with whiteboard material, and projection screens.

There are also eleven informal learning areas to provide for “sticky space” where people can drink coffee, meet and collaborate.

The facility is divided into laboratories with fixed equipment, industrial workshops, learning spaces and offices.

The whole facility is accessible to a forklift, and the workshops, learning areas, laboratories, and offices form a hub. It is therefore possible to present a class, using multiple spaces, and to transport large models between workshops and laboratories.

It was decided from the beginning to have the minimum computer laboratories. The whole facility is designed to be computer friendly. Most areas will soon be supported by Wi-Fi, and all students to be equipped with notebooks. Translation services are also provided in all lecturing areas.

Conclusion

QFD proved to be a useful tool to capture diffuse and varied user requirements, and to link them with innovative solutions based on new educational strategies. Good project management ensured that the final design fitted in the budget, and were finished on time.
This project is also noteworthy because of the level of involvement of academics and other users in the planning, and execution of the project.

References


Common Sense in a Common First Year Engineering Course: Exploring the Implications of the ECSA Exit Level Outcomes and the New National Senior Certificate on First Year Engineering Education in South Africa

Christo Kriel
Academic Development Unit, Faculty of Engineering and the Built Environment, University of the Witwatersrand, South Africa.
christo.kriel@wits.ac.za

Introduction
Internationally in engineering education a number of challenges are generally recognised: declining standards of academic preparation of incoming students and low/declining graduation and retention rates being some of the main ones. Simultaneously a highly competitive global industry is demanding graduates able to cope with new challenges. Amongst others, two curricular responses have emerged: the introduction of common/integrated curricula, and a shift towards problem/project-based learning.

This paper firstly looks at what a common first year approach entails as well as how the idea of “common sense” can be clarified in order to use it meaningfully in the context of a first year course. Next the ECSA (Engineering Council of South Africa) outcomes are examined with reference to how this idea of “common sense” can be applied toward the attainment of the outcomes. Finally the practical possibilities of such a course are examined and a structure for a common sense course is proposed.

In a common/integrated first year curriculum related topics are learned simultaneously, thus promoting a broad level of understanding, reinforcing common concepts and improving retention of material. Repetition of material is avoided, allowing concentration on areas in which students have difficulty. Curricular space is created allowing engineering related problems to be met early, the relevance increasing motivation. This curriculum arrangement allows for informed choice of area of specialisation.

Due to past (and present) inequalities in education, South African engineering faculties are faced with large numbers of inadequately prepared students qualifying for tertiary study without a shared understanding of the required rationality and logic for successful study of engineering disciplines. A common first year in South Africa thus needs to go further than similar international courses: it needs explicitly to establish a shared (common) sense of what it means to think and act rationally.

In this paper I use “common sense” in two ways: “Common”, meaning “shared”, as in the above paragraph, and also the usual meaning of “practical, no nonsense type reasoning”, the type of reasoning for which engineers have become famous in the popular mind.

During 2010 it was decided at the Wits Faculty of Engineering to explore a common first year in which the service courses (Mathematics, Physics, Mechanics and Chemistry) remained relatively unchanged, but amalgamating school-specific courses into a single common first year course “... in which students will learn basic liberal arts, philosophical, technological and social conceptions and skills” (Zietsman-Thomas, 2010).

Initially this course was envisaged to include three main components – Language; Graphics and Design; Engineering design and modelling. The latter component would incorporate a
“common sense” module, targeting basic mathematical, arithmetical and critical thinking as well as problem solving.

This paper examines the ECSA outcomes (ECSA, 2003), to establish what “common sense” should entail in a “well-designed engineer”, exploring practical possibilities to inculcate common sense in first year engineering students. Implications of the school curriculum for curricular content will be investigated. The common first year solution should not be seen as separate from a problem-based curriculum structured around design problems (the “design” approach to engineering education).

General: What the Outcomes say

Common sense involves Problem Solving and Critical Thinking (ECSA Exit Outcomes 1, 2, 7 and 9), the two coming together in solving engineering problems by thinking like a mathematician and a natural scientist while solving real world problems within a reasonable budget and time frame.

Problem Solving

Whereas, at first year level, Outcome 2 refers quite specifically to subject knowledge in the four content courses, Mathematics, Physics, Mechanics and Chemistry, Outcome 1 refers to the general ability to solve problems by applying various strategies. This talks directly to what is included under the idea of common sense.

Common sense involves deducing the logical consequences of a problem situation in order to propose solutions. This requires a ready store of "problem solving heuristics" as well as practical experience of strategies that work in different situations.

Problem solving strategies include:

General strategies or heuristics such as modelling (graphically or mathematically), analogy (have I encountered a similar problem before?), simplifying and then generalising, or taking an investigative approach.

Engineering specific approaches involve breaking a complex problem into smaller manageable units represented by an approximation of the real situation (Shaw, 2001).

Critical Thinking

Exit Outcomes 7 (critical awareness of the impact of engineering activity on social, industrial and physical environment) and 9 (sourcing and evaluating information; accessing, comprehending and applying knowledge acquired outside formal instruction; critically challenging assumptions and embracing new thinking) require a common understanding of rational thinking and argument (critical thinking skills) – an “informal” logic component looking at the structure and analysis of arguments. Engineers are required not only to analyse and create arguments around scientific issues, but also to analyse issues and arguments around social and environmental impact.

Given the interdisciplinary nature of engineering problem solving, critical thinking involves critically analysing general forms of argument (e.g. deductive and inductive arguments) as well as investigative processes in the natural sciences (e.g. problem and causal hypothesis formulation, building models by analogy etc) and, given the uncertainty of many problem solving situations, analysis of the structure of statistical arguments (critical evaluation of arguments based on statistical correlation, generalization and causality).
Practical possibilities

The following structure for a common sense course is proposed:

i) General introduction to structures and analysis of arguments

ii) How do mathematicians think? An introduction to formal axiomatic systems with specific reference to Euclidean geometry and deductive logic. This gives the opportunity to cover the geometry that should have been done at school and to develop spatial reasoning.


v) How do engineers think? Here the problem solving and design processes come together. Problems should highlight common heuristics used by engineers; measurement and error; approximation; judging the reasonableness of results.

Conclusion and Recommendations

This interpretation of a “common sense” module in a common first year engineering course dovetails with the ECSA exit outcomes and forms a solid foundation for thinking skills required of engineers in their further professional training and careers.

The context of this model may be specific to the original requirements set by Wits FEBE, but using the ECSA outcomes as a guiding principle allows the conclusions to be generalised. Dym et al (2005), for example, examine different aspects to design thinking, designing systems and making design decisions and the implications for engineering, yet come to much the same conclusion for practical requirements.

References


Chemical Engineering at Moi University: Curriculums from Past to Present and Challenges of the Future

Anil Kumar¹ and Henry Kirimi Kiriamiti²

Department of Chemical & Process Engineering, School of Engineering, Moi University, Kenya

¹ akumar@mu.ac.ke, ak3900@yahoo.com, ² kiriamiti@mu.ac.ke, kiriamiti@yahoo.com

Moi University was established in 1984 as the second public university in Kenya. Faculty of Technology was originally started with two departments viz., Production Technology, and Electrical & Communications Technology. Department of Chemical & Process Engineering was started later, in 1991. Moi University Act and Statutes state that the Senate, through the office of Chief Academic Officer, is the authority for all academic issues that includes the curriculum development and approval (Moi University Calendar, 1996).

The 8-4-4 education system in Kenya was launched in 1985 (Chris Wosyanju, n.d.). Initial curriculum for a 5-year degree programme was developed in the 1991. Department of chemical engineering of University of Dar-es-salaam, research institutions and industries from Kenya participated in developing a programme to train graduates to serve chemical industries in the country. The first curriculum developed thus underwent a thorough vetting by various stakeholders.

In 2004, it was felt by the Faculty Board that a period of five years for a degree programme was on a higher side, and keeping in view the trends in the world, it needed to be reduced (Engineering Education, n.d.). A four-year degree programme was developed which was equivalent to the five-years programme. However, this idea had to be abandoned due to problems of accreditation.

The current curriculum is the one revised in 2006. The process was mostly in-house, external input was through the External Examiner only, which was minimal. Term ‘technology’ in the awarded degree was replaced by ‘engineering’, laying more emphasis of engineering science rather than on technology.

The paper gives a detailed curriculum development process as required by the university Senate (Procedure for Curriculum Development MU/ACD/2/26A 2010), and the problems of logistics in meeting them. It also discusses the accreditations by the Commission for Higher Education and the Engineers Registration Board of Kenya (Cap530: The Engineers Registration Act, n.d.). The challenges faced by the department due to the proposed Engineers Bill 2009 which intends to ‘harmonize engineering programmes’ in the country, are outlined (Njorraw, 2011). Problems of diversification, of starting new related engineering disciplines, have been discussed.

Staff retention is a critical issue affecting the quality of teaching and research. Possible causes of high mobility are the remuneration and work environment. Issues of optimum teaching hours is another contentious matter. Class timetable analysis shows an occupancy exceeding 75%, and some experts feel that we ‘over-teach’, which may be counterproductive (Stakeholders Comments on Review of the Five-Year Bachelor of Technology Degree Programme, 2009).
School of engineering admits two categories of students, government-sponsored (GSSP) and privately-sponsored (PSSP). Admission places for GSSP students, who are eligible for state higher-education-loan, are limited and only very meritorious ones are thus taken (Luke Anami, 2011). PSSP students are self-sponsored and fee-paying, with a fairly relaxed admission requirement. This mix up of GSSP and PSSP students in the class results in disparity between their academic performance. Academic performance data for both category of students for years 1 to 5, comprising of 15 core courses, for 7 academic years, have been analyzed to show that PSSP students perform poorly as compared to GSSP students. Some PSSP students who were discontinued on academic grounds have gone overseas to earn an equivalent engineering degree, proving their intellectual capability. High dropout rate of PSSP students also adversely affects the income generated to the school as they are fee-paying. The high failure rates of PSSP students may be addressed through a revised curriculum (although this has its own limitations), and through a better teaching method. Hence a challenge is to come up with more efficient teaching methods in order to reduce the gap between GSSP and PSSP performance.

Problem-based-learning (PBL) (Problem Based Learning, n.d.) has been identified as a new teaching method which has distinct advantage on traditional class room teaching and memory-recall examinations. This method makes the students independent learners and instils skills needed to meet the challenges in real life, and the assessment is through a self-assessment by the students and comparison with their peers. School of Medical Sciences at Moi University has already successfully adapted PBL to their curriculum. However, whether PBL will suit engineering discipline here is yet to be tested, problems being lack of PBL oriented teaching material and insufficient staff. First curricula was designed to address national needs and hence another challenge is to ensure that the revised engineering curriculum also caters to the needs of internationalization. Traditionally ‘design’ is a key word in engineering education, however, the new era is of information technology wherein engineering students are trained to design, fabricate, and analyze engineering problems keeping the internet, innovation and internationalization (the 3Is) as a strategy (Kumar et al., 2004). However, the limited internet bandwidth constraints a liberal use of internet related learning; and it is debatable whether a developing economy like Kenya should prioritize to ‘internationalize’ its engineering curricula.

References


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Extended Abstract


Stakeholders Comments on Review of the Five-Year Bachelor of Technology Degree Programme.(2009). Curriculum Review Workshop 18th -20th February 2009, Department of Civil & Structural Engineering, School of Engineering, Moi University.

Curricular Reform in Chemical Engineering Education at the University of Dar es Salaam, Tanzania

Karoli Nicholas Njau\textsuperscript{1} and Osmund Kaunde\textsuperscript{2}

\textit{Chemical and Process Engineering Department, University of Dar es Salaam, Tanzania}

\textsuperscript{1}knjau30@yahoo.com, \textsuperscript{2}kaunde@udsm.ac.tz

Introduction

Chemical engineering discipline is a key discipline for any developing country. The chemical engineering curriculum requires regular reviews to make it relevant. The Chemical Engineering education at the University of Dar es Salaam (UDSM) has faced many challenges and undergone many changes since its inception in 1979. These challenges have largely been addressed through various reviews carried out every five years. These reviews included tracer studies as important input.

Initially the programme had two streams of chemical engineering and process engineering. The establishment of the streams did not consider the market conditions at the time and no sensitization was done. The markets for chemical engineering graduates which were dominated by state owned industries did not know where to place the new professionals. The first review of the programme done in 1986 following a Tracer Study revealed that overspecialisation in the program was doing harm than good. It was realised that what the country needed was an engineer who could manage production in the processing industries. The two streams were therefore merged and became what is currently known as Chemical and Process Engineering (CPE) program.

There has been more curriculum reviews involving Tracer Studies in 1989, 1995, 2002 each one providing feedback to the University about the quality of its graduates, relevance of the programmes and improvements needed both in structure and content. At the time of writing this Abstract the CPE program, like other programs in the College of Engineering and Technology (CoET) at UDSM is being reviewed taking into account the findings from the 2010 Tracer Study. The aim of this paper is show how the tracer study results are shaping the current curriculum review exercise.

The Current Tracer Study

The 2010 Tracer Study involved Graduate and Employer surveys. 157 former Graduates and 77 Employers were interviewed. There were a total of 45 questions for the Graduate and 23 for the Employer survey, covering different aspects. Below are some highlights of the Tracer study results.

As seen in Figure 1 nearly 20\% (31 respondents) of Graduates were from Chemical and Process Engineering programme. However, when the Graduates were asked to indicate the engineering discipline they would choose if they were given another chance to study, only about 7.6\% (9 respondents) indicated that they would choose Chemical & Process Engineering. This shows that majority of the current chemical engineering graduates would choose another field if that opportunity was available.

The study established that marketability of the program is a major drive for the choice of field of study (61.3\% of respondents) followed by easy of self employment (19\%) and interest in the field (19\%). (Figure 2).
Extended Abstract

Figure 1. Distribution of areas of specialization of graduate engineers Versus Number of Respondents; and Preference of programs

Figure 2. Reasons for choosing engineering field

Regarding relevance of subjects taught in the CPE program, respondents were asked to show the relative importance of the compulsory subjects with respect to applications in work place. The results are shown in Figure 3. Furthermore Figure 4 shows a similar analysis but for common courses offered to other undergraduate programs. In general all the courses were found to be reasonably relevant, although there were specific comments to be addressed in some of the courses.
In addition to the taught courses, the engineering programs at UDSM include: Research Projects in the final year; Laboratory Practicals; Workshop Training in the first year, and Practical Training in Industry (PT).

With regard to the final year Research Project, and Laboratory Experiments, graduates indicated that insufficient funds for doing the project (80.5%) was the most prominent problem encountered followed by inadequate laboratory equipment and tools (54.7%) (Figure 5).
At CoET undergraduates go through Workshop Training during which they gain some hands on experience. Graduate engineers were asked to mention major problems encountered during training in the workshops. As shown in Table 1 the three most prominent problems encountered included short training time per workshop (62.9%) and inadequate materials, tools, equipment and teaching aids (59.7%) and lack of protective gear (47.2%).

<table>
<thead>
<tr>
<th>Problem encountered</th>
<th>Freq.</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short training time per workshop</td>
<td>100</td>
<td>62.9</td>
</tr>
<tr>
<td>Inadequate materials, tools, equipment &amp; teaching aids</td>
<td>95</td>
<td>59.7</td>
</tr>
<tr>
<td>Lack of safety gadgets and protective gears</td>
<td>75</td>
<td>47.2</td>
</tr>
<tr>
<td>Inadequate number of qualified workshop /teaching staff</td>
<td>51</td>
<td>32.1</td>
</tr>
<tr>
<td>Poor working environment</td>
<td>43</td>
<td>27.0</td>
</tr>
</tbody>
</table>

The Tracer Study identified also the most relevant workshops to chemical and process engineering programme to be Chemical and Process; Electrical; Electronics and Welding. Workshops that were considered of less importance are Carpentry, Masonry, Machine tools and Bench workshop.

Employers were asked to indicate their views on the training period for engineers before they gain the required knowledge and skills. Figure 6 shows that majority of employers (72%) were of the opinion that the time required for training (i.e. 4 years) was just adequate.
Figure 6. Opinion on duration of training engineers at undergraduate level

Regarding additional training areas attributes that that engineer graduates need to be trained in order to prepare them for occupying managerial positions, more than half of the respondents (51.55%) suggested inclusion of general management course followed by communication skills (15%)(Table 2).

Table 2. Additional training areas for engineers to be considered at undergraduate level

<table>
<thead>
<tr>
<th>Additional areas for the engineering course</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>General management</td>
<td>52</td>
</tr>
<tr>
<td>Communication skills</td>
<td>15</td>
</tr>
<tr>
<td>Human resources management (HRM)</td>
<td>12</td>
</tr>
<tr>
<td>Business administration</td>
<td>6</td>
</tr>
<tr>
<td>Computer skills</td>
<td>6</td>
</tr>
<tr>
<td>Entrepreneurship</td>
<td>6</td>
</tr>
<tr>
<td>Perceptive/intuitive skills</td>
<td>3</td>
</tr>
<tr>
<td>Economics</td>
<td>3</td>
</tr>
<tr>
<td>Quality management</td>
<td>3</td>
</tr>
<tr>
<td>Procurement management</td>
<td>3</td>
</tr>
<tr>
<td>Financial management</td>
<td>3</td>
</tr>
</tbody>
</table>

Conclusions from the tracer study of 2010

Important information from the 2010 Tracer Study to inform the current chemical engineering curriculum review include:

Generally marketability of chemical engineering programmes is in question. The current review exercise should strengthen the curriculum to make it more responsive to current market demands.
The current CPE compulsory and specific courses find some application by the graduate engineers at their work places. Specific recommendations for respective courses have been identified and shall be addressed during the curriculum review.

The market suggests that CPE graduates should be equipped with general management skills. This can be accommodated within the current review.

Time for doing the Research Project is insufficient. The department is reviewing the total load of the programme and move some of the courses especially in semester 8 to lower semesters to allow room for students do research.

Insufficient funds and inadequate laboratory equipment and tools are the major bottleneck to the execution of Research Project and Laboratory experiments. The department should continue to solicit increase of research funds from the government but also embark on soliciting funded research projects to supplement student research funds.
Turning Numbers into Footprints in Engineering Education

Tebatso Michael Phala

Academic Development Unit, Faculty of Engineering & the Built-Environment, University of the Witwatersrand, South Africa.

tebatso.phala@wits.ac.za

The last decade has seen an unprecedented increase in the number of students enrolling for engineering programs at tertiary institutions. Although this is a significant step in the right direction in an attempt to address the huge shortage of qualified professionals in engineering and the built-environment, it does bring with it a few challenges, including the issue of large classes.

Of course with large number of students at first year level each year, it becomes challenging for faculty staff to engage in deeper interactions beyond a packed classroom. Due to large volumes of teaching, assessing and administration that form part of modern teaching, it is easy to unintentionally reduce students to just student numbers and grades without a personal knowledge of each student and her needs.

We know that different learners learn at different rates and have different learning needs. Yet our current paradigm of education and training entails teaching a large group of learners the same content in the same amount of time. Why? One reason is that group-based learning represents logistical and economic efficiencies even though it does not do a good job of meeting learners’ needs (Reigeluth, 1999).

Without the staff members being able to get a brief overview of each student, it becomes difficult to meet the students’ individual needs. Group-based teaching is important in dealing with the large enrolments issues and would have been appropriate if universities were functioning like mass-productions plants. But surely modern times require that each graduate should also have a vast set of individual skills that can’t be mass-produced. Is teaching that does not consider each student’s individual needs and background into consideration still sufficient? Are there no supplementary and complimentary resources and tools that can be used to ensure that teaching remains consistent with the dynamic needs of each student?

In addressing this problem, the Academic Development Unit (ADU) in the faculty of Engineering & the Built-Environment at the University of the Witwatersrand maintained that despite the often overwhelming enrolments at first year level, good teaching is often a product of having a good sense of the students. As a result, from 2008 the ADU implemented a process of designing and maintaining a profile for each first-year student in the faculty, comprised of as much useful data as possible.

The profiles include some biographical data that helps in identifying each student. There is also some academic background such as previous academic achievements that gives an indication of each student’s potential. Also included is the student’s current enrolment status (degree code, whether repeating a course or not, etc.) and current academic activities (mainstream and ADU’s).

To the uniformed eye, the data collected for each student’s profile may seem like just a bunch of numbers but through the ADU these numbers have been turned into significant footprints made by each student. The profiles have helped the faculty to know each student’s past, current status and sometimes even a potential future as far as studies are concerned. Similar
to real footprints, the data in the profiles indicates the student’s background, what they are currently doing and sometimes not doing and what could be potential consequences unless some form of intervention is put in place.

So instead of just using the profiles to explain what happened to the students, the data is primarily useful in identifying students’ current needs (academic, social, financial). It is a useful and suitable tool that guides the ADU and other members of faculty in constantly adjusting teaching to aid students who need such. So, instead of being reactive when it is already late, the data is used in creating proactive teaching. Data collected from regular diagnostic tests, quizzes, problem-solving exercises and the use of personal response systems (clickers) help in identifying concepts that some students struggle with or pick up students that might be trailing behind the rest of the group.

The profiles have also been used to source funding for needy students, to regularly keep track of each student’s performance, to check if students are making use of intervention programs in place, to evaluate the effectiveness or ineffectiveness of the various intervention programs in place, to keep an eye on courses in case of significant shifts in trends or to even inform faculty and council decisions when dealing with excluded students’ appeals at the end of the year.

One unexpected outcome of keeping these profiles has been how it has motivated some of the students. Some students have shown a significant improvement in their studies after realizing that someone or some people were regularly keeping an eye on their academic activities. For some, it appears to have brought about a sense of knowing that they are accountable and that there are consequences for failing to maximize on the opportunities given. A simple example is that of a first-year engineering student who came to consult with the ADU at the end of the first quarter in 2010. He had failed all his first set of tests with a 41% aggregate but finished with a 61% aggregate and passed all his courses.

Although it is still early to see clearly the overall effects, the glimpses of motivated students, improved retention rate at 1st year level as a result of the different intervention methods in place (e.g. academic, financial, social) have motivated the ADU to stay the course. As Perkins put it, “Good teaching demands different methods for different occasions”, the profiles help in identifying the occasion and then the teaching required.

References
Experimental Design for Analysis of the Discrepancy in Predicting the Academic Performance between First and Fourth Year Engineering Studies

D.E. Serfontein¹, E.C. Hattingh² and J.I.J. Fick³

¹School of Mechanical and Nuclear Engineering, North-West University, South Africa; ²Faculty of Engineering, North-West University, South Africa; ³Faculty of Engineering, North-West University, South Africa

¹Dawid.Serfontein@nwu.ac.za; ²Elza.Hattingh@nwu.ac.za; ³Johan.Fick@nwu.ac.za

Introduction

Engineering lecturers often remark that there are some students who manage to pass the first three years of the B.Eng. programme, but still demonstrate poor engineering aptitude in the final year as the programme emphasis changes from theoretical science to engineering application, design and synthesis.

Failure in the final year may cause severe problems for students. Alternatively, scraping through may launch students into a career for which they lack a fundamental talent, thus setting them up for failure.

The opposite situation is also occurs. Some students struggle to pass the first two years of theoretical study, only to blossom into excellent engineering students towards the senior years. These early struggles may cause termination of study by potentially good engineers.

A study at the NWU confirmed that, while matric results in mathematics and science correlated relatively well with first year engineering grades, this correlation weakened in the later years, especially in subjects that require higher cognitive skills like insight, logical reasoning, generalisation and application skills. Similarly, some of the results of a longitudinal study suggest a low correlation between the academic performance of the first and later years. Using matric results as the sole selection criterion to predict success in engineering studies may thus be misleading.

Therefore the NWU has created a set of engineering tests in which the emphasis was switched from mainly assessing knowledge to mainly insight, in order to assist in identifying potentially successful engineering students. This engineering test showed a stronger correlation with second, third en fourth year grades (Hattingh EC, 2011).

The underlying hypothesis of the present work is that this weaker correlation between early and latter years is caused by assessment levels through matric and up to the first year of university that reward route learning, requiring little insight and application, while later years of engineering study require and reward students with an ability for application and engineering insight.

Theoretical basis

The mismatch between student performance in the early theoretical studies and aptitude for problem solving in engineering design and practice in the later years, is widely perceived (Banios, 1991; Phang et al, 2010). Therefore several programmes have been launched successfully in which the traditional design and project orientated subjects of the latter years were integrated into the curricula from the first year (Weber et al, 2000), and even high school level (Phang et al, 2010), often with strong government support (Crane et al, 1997).
Aspects such as team work, professional communication and creative problem solving are included in these first year programmes. Preliminary results indicated that students in these integrated programmes outperformed students in more traditional programmes (Weber et al, 2000). In order to facilitate this integration, engineering design and project work are taught in ways that require less theoretical knowledge. The required knowledge is also taught on a just in time basis (Shuman et al, 2008). Several programmes have been launched to change the way in which for instance mathematics (Goulet, 2002) and physics (Srinivasa & Bassichis, 2006) are taught in the early years, in order to enhance engineering insight. Assessment practices are also being adapted to stimulate creative thinking and innovativeness (Gawain, 1974).

In order to effectively stimulate engineering insight/aptitude, it is necessary to define engineering insight (Heywood, 2008). The definition by the Chinese engineer, Li, seems particularly helpful: “The essence of scientific activity is discovery, the essence of technological activity is invention, and the essence of engineering activity is creativity or the design of artefacts.”

For the purpose of this study, the outcomes set by ECSA (2004) will be used as the goals of the engineering education process and will be applied to measure the degree to which the theoretical subjects in the early years contribute to attaining these outcomes in the latter years.

**Experimental design**

In order to analyse this phenomenon in greater detail, with a view to possible remedies, the following longitudinal experimental design is proposed:

1. The 25% best and the 25% poorest academic performers in the fourth year Mechanical Engineering class will be selected. Subjects that specifically require high levels of engineering insight will be selected.

2. Their grades will be compared to their first year performance in the theoretical subjects, such as Mathematics, Physics and Applied Mathematics. Outliers will be selected, i.e. students for whom their first year’s performance either strongly over or under predicted their fourth year performance.

3. The first year examination answer sheets, as well as the question papers and memorandums of the chosen subjects will be graded in terms of Anderson and Krathwohl’s Taxonomy (2000). This is a more recent adaptation of Bloom’s taxonomy for the cognitive domain and is useful to determine the level of higher order thinking skills required by each examination question.
   a. From a statistical analysis of the relationship of the grading of questions and marks obtained, the initial hypothesis, that the discrepancy between first year and latter year performance was due to a switch from the assessment of mainly the ability to memorise to the assessment of engineering insight, will be tested quantitatively.
   b. From the qualitative analysis of students’ examination answers, it will be determined whether the hypothesised discrepancy between memorisation ability and insight was observably demonstrated in students’ answers.

4. These findings will then be used to design appropriate interventions in the education process. It is expected that these will focus on replacing the rewarding of route...
learning with rewarding engineering insight from the first year. Also on integrating more design and project work into the curricula of the early years.

Conclusion

The study is expected to provide important inputs towards optimising the content of engineering syllabi and especially assessment design.

Improved throughput in the latter years of study is one of the benefits that can be expected, but improved throughput in the early years for those students who have good insight, but poor memorisation ability is also expected. Engineering graduates with higher levels of engineering aptitude may be produced, as well as earlier identification of students who have less potential to become successful engineers, thereby facilitating an earlier switch to other career options, which may save the country significant amounts of money and these students much personal frustration.

References

Factors Impacting on the education of African Engineering Students at Vaal University of Technology

James Swart

Department of Electronic Engineering, Vaal University of Technology, South Africa
jamess@vut.ac.za

Many factors may contribute to the poor academic success of students in higher education, including stress or anxiety, time management skills and deficiency needs. This paper presents scientific literature substantiating the above claim along with relevant empirical data obtained from questionnaires completed by senior electrical engineering students at a University of Technology. The empirical study incorporates an ex-post facto study involving a pre-experimental/exploratory design using descriptive statistics. The results of this research were applied to various tests which indicated a statistically significant relationship between two of the factors (stress or anxiety and deficiency needs) and the final throughput rate of a module termed Design Project III, which served as the case study for this research. A few recommendations are made as to how African engineering students can reduce their stress levels, improve their time management skills and satisfy their deficiency needs.

Introduction

Higher educational institutions in South Africa are currently experiencing low throughput rates in many of their educational programmes, including electrical engineering. This has a negative impact on government subsidies received from the Department of Higher Education and Training, and subsequently on the purchasing of new equipment and technologies required in engineering education. Many factors contribute to this low throughput rate, which may subsequently be linked to the education and academic achievement of students, and include stress or anxiety, time management skills and deficiency needs.

Factors impacting on the academic achievement of students

Stress is registered in the brain as a threat that causes a stress response in the body and is often produced when events and responsibilities exceed one’s coping abilities (Lazarus, 1993). Various causes of stress (stressors) exist, which include heavy workloads, insufficient skills, taking tests and the constant pressure of studying (Clunies-Ross et al., 2008; Swart, 2008; Hystad et al., 2009). For many students the end results of these stressors are elevated levels of anxiety and depression (Bouteyre et al., 2007), poorer academic performance (Lewis & Frydenberg, 2002; Akgun & Ciarrochi, 2003; Kaplan et al., 2005; Byrne et al., 2007) or departure from academia (Daugherty & Lane, 1999).

Poor time management is a perceived cause of examination failure or poor academic performance (Macan et al., 1990; Britton & Tesser, 1991; Burt & Kemp, 1994; Fitzgibbon & Prior, 2003; Ling et al., 2003). It is evident in people who are regularly late (Swart, 2007) and may even cause academic stress (Misra & McKean, 2000). Poor time management skills may also lead to more pressure to plagiarize (Hart & Friesner, 2004) and causes students to be pushed into using a surface approach to learning (Thomson & Falchikov, 1998). It is often a symptom of over-confidence (Blair, 1992). Many undergraduate students report problems with time management when it comes to writing term papers, studying for examinations, and keeping up with weekly reading assignments.
Maslow’s hierarchy of needs is divided into two levels, being the lower levels called deficiency needs and the higher levels called growth needs (Prescott & Simpson, 2004; Anderson, 2005; Majercsik, 2005; Zalenski & Raspa, 2006; Litwack, 2007). The lower levels (health, safety, belonging and esteem) represent the basic human needs for physical well-being. These needs must be partially satisfied before students can be motivated to pursue satisfaction of the higher levels where a person fulfils his or her personal potential (Brown & Cullen, 2006). Numerous research articles have identified the importance of motivation in attitudes towards work and in performance (Bredillet et al., 2007; Chandler et al., 2009).

Methodology and results

The case study on which this paper is based, explores the relationship between stress or anxiety, time management skills and deficiency needs of African engineering students and the throughput rate of an engineering module called Design Project III. The empirical study incorporates an ex-post facto study involving a pre-experimental/exploratory design using descriptive statistics. Two data sets were obtained to ensure reliability and validity, one for 2005 and another for 2008. The results of this research were applied to various tests which indicated a statistically significant relationship between stress or anxiety and the final throughput rate of the module Design Project III (see Figure 1). Moreover, the presence of a negative correlation indicates that a decrease in the negative aspects of stress or anxiety will result in an increase in the final throughput rate of the module, subsequently influencing the academic success of engineering students. A statistically significant relationship between satisfaction of deficiency needs and the academic achievement of engineering students was also established (see Table 1). However, the results indicated that no statistically significant relationship exists between time management skills and the academic achievement of engineering students.

![Stress or anxiety - (b) negative aspects](chart.png)

** = Correlation is significant at the 0.05 level

**Figure 1.** Negative aspects of stress or anxiety which were correlated to the throughput rate of the module Design Project III for 2005 (Data set one)
Table 1. Correlation between the questions on deficiency needs and the final individual grades of students in DES3

<table>
<thead>
<tr>
<th>Time period</th>
<th>Throughput</th>
<th>Measurement</th>
<th>Sample</th>
<th>Pearson r</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Data set one</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2005 - Aug.</td>
<td>75%</td>
<td>Test 1</td>
<td>n = 47</td>
<td>0.207*</td>
<td>0.081</td>
</tr>
<tr>
<td>2005 - Sep.</td>
<td>75%</td>
<td>Test 2</td>
<td>n = 32</td>
<td>0.466***</td>
<td>0.004</td>
</tr>
<tr>
<td>Data set two</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008 - Aug.</td>
<td>89%</td>
<td>Test 1</td>
<td>n = 53</td>
<td>0.203*</td>
<td>0.073</td>
</tr>
<tr>
<td>2008 - Sep.</td>
<td>89%</td>
<td>Test 2</td>
<td>n = 48</td>
<td>0.244**</td>
<td>0.047</td>
</tr>
</tbody>
</table>

* Correlation significant at 0.1 level; ** Correlation significant at 0.05 level; *** Correlation significant at 0.01 level

Conclusions

African engineering students may reduce their stress levels and improve their time management skills by seeking the aid of student counselling and support, especially when it comes to handling their heavy workloads. They may also make use of consultation times scheduled by their lecturers, so as to seek a better understanding of what is required of them. They also need to satisfy their deficiency needs in terms of maintaining good health and interpersonal relationships between their fellow students. These and other interventions may help students to achieve academic success, impacting positively on the throughput rates of institutions and subsequently on teaching output grants awarded by the DoHET in the RSA.

References


Academic Achievement vs. Readiness for Tertiary Education: Case Study of Engineering Students at VUT

Eudes K Tshitshonu¹ and Maurice Ndege²
¹ Department of Mechanical Engineering, ² Department of Civil Engineering, Vaal University of Technology, South Africa
¹eudes@vut.ac.za, ²maurice@vut.ac.za

Abstract
The first semester of study in institutions of higher learning is very important for the academic progress of most students. It is, for many, a first time experience of life away from direct parental supervision. The academic setup is a whole paradigm shift. Responsibilities, choices and initiatives are shifted to students, most of which show very little preparedness as they grasp with an ill-conceived notion of freedom. The current work discusses observations of shortfalls in a subject perceived difficult and presents an experimented strategy and its efficacy to support students in the particular subject with a broader view of imparting positive attitudes towards their studies as well as prospective career choices. Groups of students registered for the same subject are presented with the Flexibility to Adapt to their Learning Style, while the rest take a traditional lecture the chalk-on-board style. All students are submitted to the same final examination. The observation of both groups achievements are presented and the results tend to present that engaging the students’ initiative through the Flexibility to Adaptive Learning Style (FALS) could foster an attitude, conducive enough for better academic achievement and a better preparation for positive contribution as stakeholders in their prospective fields.

Introduction
Introductory Engineering Mechanics is a subject matter posing a lot of challenges for first semester students. From the structural integrity of parts and components of machines and civil structures, through the efficiency of power transmission systems up to the programming of processes and manufacturing time, nearly all fields of engineering borrow from the content presented in introductory engineering mechanics. Poor students’ performance is a real challenge and in some instances a gate closer for further studies as a major subject for some streams of engineering studies. Recognition of prior learning, NQF level as well as other criteria and prerequisites are used as gate-pass toward candidate admission to tertiary education programs. A valid assumption should be that those allowed into tertiary education are competent. The validity of the assumption remains questionable in the light of students approach to their studies and respective performance rates. It has been of particular interest to find out that students struggling with questions tagged “difficult” eventually realized they did not take adequate time to read questions critically enough in order to approach them against the backdrop of underlying theories. Students would mostly start solving problems without a proper grip on fundamentals and rather target textbook answers and rehearse previously solved problems. Worse, their common-sense and logic seem to turn obsolete in the race for the textbook suggested solutions. Studies become a mere memorisation of solved problems. How does one get to do research, develop and innovate without personal initiative, independent thinking or a systematic approach towards developing solutions from basic concepts and fundamentals? A proper strategy was required to prepare students to take initiatives and drive their own success.
Methodology

The amount of sources of information and available references produced everyday, is gradually shifting and has in some places already redefined the teacher/lecture’s role. Traditionally viewed as the prime source of knowledge, teachers/lecturers in today’s information age would be better looked at as a key that opens the door to domains of knowledge and experience (Dochy, 2001). The student has been given centre stage as an active stakeholder and responsible for his or her learning (Dierick and Dochy, 2001). The teacher is now the initiator and the guide in the process. S/he becomes a mentor or a coach who provides opportunities for the learners to use what they already know in order to understand new topics, thus creating a learning environment characterized by a good balance between discovery learning and personal exploration, on the one hand, and systematic instruction and guidance, on the other. Guidance would be offered in areas as curriculum design, respective career path choices as well as formatting of the content to be presented. As a stakeholder the student comes with her/his personality, preferences and eventually aptitudes. The one size fits all approach is no more the way forward especially given the multimedia propensities of today’s information age. Felming’s VARK (Visual – Auditory - Read/write - Kinaesthetic) inventory of learning styles classified students’ learning preferences into four categories: Visual preference which includes the depiction of information in maps, diagrams, flow charts and all the symbolic arrows; Auditory perceptual mode that describes a preference for information that is "listened to or spoken"; Read/write preference for information displayed as text and Kinaesthetic modality which refers to the perceptual preference related to the use of experience and practice (Narayanan, 2009).

Mustafa and Sharif (2011) conducted a study showing that students taught using the system with adaptation to learning style performed significantly better in academic achievement than students taught the same material without adaptation to learning style. Narayanan (2009) advocates for the fact that technology should be intelligently implemented as a valuable instructional tool that can accommodate diverse learning styles of 21st century students and acknowledges the fact that it is very important to create significantly different learning environments, particularly for engineering students. The VARK approach is quoted as beneficial and implemented in diverse fields of education. Technology offered the leverage to design a learning environment and facilitated our attempts to accommodate students from different backgrounds, with different learning styles and preferences. The VARK approach is however not the panacea to solving all teaching/learning challenges. A totally different approach is presented in a study aimed at assessing whether learning-styles-based instruction practices could be supported by scientific evidence (Pashler et al., 2009). Pashler et al. concluded that any credible validation of learning-styles-based instruction still required robust documentation of a very particular type of experimental finding with several necessary criteria. No adequate evidence base, in their findings could to justify incorporating learning-styles assessments into general educational practice. The observation made in the experiment conducted in the current study did not intend to administer the VARK classification test and sort students according to their respective learning preferences. The subject content was rather redesigned in a format that blends all learning preferences. Every student in the FALS group was supposed to attend traditional class presentations where the lecturer made oral presentation and used chalk and board. Students would listen (A) and verbally interact in class discussions. Furthermore, during lecturers, in order to demonstrate the theory part under discussion, one student would be designated to solve a problem on the board, another student would be designated to Read the applicable theory (R) and the rest of the class invited to participate and discuss the implementation of the read-out theory while attempting the same...
problem in their notepads (K). The traditional contact session was complemented by a set of online activities where student would be expected to take ownership by individually attempting interactive tutorials (R and K). The online sessions contained a set of slideshows as theory reminder (V and R). One class session a week was dedicated to laboratory activities. Students would construct physical models illustrating selected problems (K) in order link the theory to physics of problems and eventually derive appropriate model, before attempting numerical solutions.

**Results and Discussion**

The sample group used to extract data for this study was made of a total of 671 students registered for the subject. A head count of 104 (15%) out of a total of 671 registered students attended classes where Flexibility to Adaptive Learning Style (FALS) was offered. All students wrote the same final exam which carried 50% weight of the overall final result. The other 50% came from the average work presented during the semester (Semester Tests and Laboratory practical work). A student with an overall average above 50% passes the subject provided a minimum of 40% is earned during the final examination. A student with 40% in the exam passes the subject if s/he achieved 60% as year mark for admission to final examination, whereas a student admitted to the final exam with 70% year mark but achieving 30% in the exam is not granted a pass mark. Due to logistical constraints, assessments for students’ admission to the final exam were conducted in respective groups. Only the final examination was handled as common assessment, identical for all groups. Results presented in this discussion are based on final examinations only, given the above mentioned reason. Table 1 and figure 1 show results for students passing the subject (meaning an overall average of 50% with at least 40% in the final exam) from both groups. A total of 52% of students from the FALS group met the requirement to write the final exam and 46 % of the bunch passed the subject, as per the exam results breakdown presented in table 1 and figure 1. From the group attending traditional classed, 68% were admitted to write the final examination, 28% managed to pass the subject.

**Table 1. Comparative Breakdown of Pass Results for students passing the subject**

<table>
<thead>
<tr>
<th>Percentage Ranges</th>
<th>Adaptive</th>
<th>Traditional</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 - 49%</td>
<td>9</td>
<td>15</td>
</tr>
<tr>
<td>50 - 59%</td>
<td>27</td>
<td>7</td>
</tr>
<tr>
<td>60 - 69%</td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>70 - 79%</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>80 - 89%</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>46</strong></td>
<td><strong>28</strong></td>
</tr>
</tbody>
</table>
Figure 1. Comparative Breakdown of Pass Results for students passing the subject

The statistical distribution of students passing the exam is presented in table 2 and figure 2. Collected data indicate that the majority of students from the traditional class presentation groups passed the subject with their final examination result within the 40 to 49% range. The majority of students passing the subject in the FALS group lie in the 50 to 59% range.

Table 2. Distribution of students passing the subject into percentage ranges

<table>
<thead>
<tr>
<th>Percentage Ranges</th>
<th>Adaptive</th>
<th>Traditional</th>
</tr>
</thead>
<tbody>
<tr>
<td>40 - 49%</td>
<td>19.6</td>
<td>53.6</td>
</tr>
<tr>
<td>50 - 59%</td>
<td>58.7</td>
<td>25</td>
</tr>
<tr>
<td>60 - 69%</td>
<td>8.7</td>
<td>17.9</td>
</tr>
<tr>
<td>70 - 79%</td>
<td>8.7</td>
<td>3.5</td>
</tr>
<tr>
<td>80 - 89%</td>
<td>4</td>
<td>0</td>
</tr>
</tbody>
</table>

Figure 2. Distribution of students passing the subject into percentage ranges

Conclusion

It is still early to draw significant conclusions on the efficacy of the method. However, the intermediate results presented in tables 1 and 2 as depicted in figures 1 and 2 seem to indicate that Flexibility to Adaptive Learning Style (FDLS) could provide means of engaging students’ own initiative. As in any successful project, having all stakeholders to share the vision of the project makes it easier to achieve better deliverables, with optimal resources. The authors believe that the successful implementation of FALS would prepare students for further years of studies and develop the right work ethics for their prospective career paths.
References


Educating the Future Mining Engineering Practitioner: Real Time Mining Engineering Education for Real Time Mining Engineers

Ronny Webber-Youngman¹, Ronel Callaghan² and Estelle Drysdale³

¹Department of Mining Engineering, ²Department of Education Innovation, ³Department of Education Innovation, University of Pretoria, South Africa

¹ronny.webber@up.ac.za, ²ronel.callaghan@up.ac.za, ³estelle.drysdale@up.ac.za.

Introduction

This paper describes the department of Mining Engineering at the University of Pretoria’s (UP) research and the educational approach developed to address the variety of challenges impacting on teaching mining engineering at a residential university in South Africa. An action research process that spanned the last ten years developed teaching and learning solutions, based in active and whole brain teaching and learning and grounded in the CDIO (Conceptualize, Design, Implement and Operate) concept. As a result of this research the current aim of the department of Mining Engineering is to apply a holistic teaching approach by introducing multiple integrated interventions with regards to teaching and learning strategies.

Methodology

Action research is an ideal strategy to follow when designing educational solutions, firstly because it follows a repetitive spiral of planning, acting, observing and reflecting to create continuously better solutions to problems in practice (Callaghan, 2008, p. 134 – 138). Secondly, according to Zuber-Skerritt (2005), “action research is participatory collaborative research which typically arises from the clarification of some concerns generally shared by a group”. This supports the development process in the Department of Mining Engineering, as all lecturers, as well as support staff and students are involved in this initiative.

During the first phase of this research, prior to 1999, several teaching and learning challenges were identified and various low level solutions were developed. In the second phase, the focus was on improvement of these solutions, as well as development and piloting of a variety of other interventions. These interventions are discussed in more detail in the next paragraphs. The current phase is focusing on implementation, improvement, training and support, as well as on-going critical evaluation of interventions, with the aim to improve and identify other challenges and needs.

Educational foundations

The educational foundations of this initiative are grounded in the context of collaborative, active, whole brain teaching and learning, as well as in the principles of the engineering teaching initiative of CDIO.

The whole brain teaching and learning concept was developed by Ned Hermann. According to his findings the thinking brain is divided into four quadrants or “modes of knowing”. These are the left cerebral hemisphere (A – logical, rational), left limbic hemisphere (B – organized, procedural), right limbic hemisphere (C - emotional, interpersonal) and right cerebral hemisphere (D – visual, experimental). These “modes of knowing” directly influence learning, and should be taken into consideration when planning for teaching and
learning – not only to support a learner’s brain preference, but also to strengthen the activities of the other quadrants – in order to develop a more balanced whole-brain approach (Herrmann, 1993). According to Farmer (2004), traditional teaching and learning has favoured the left hemisphere’s typical logical and sequential methods, and it is important that lecturers should manage the learning process to also develop the right hemisphere.

The active teaching strategy is based on the principle that students are actively involved in their studies and that teaching and learning activities – both in and out of the classroom – are structured to encourage this.

In the engineering context, the CDIO concept has developed over the past years in an answer to concerns from industry that graduating engineering students, “while technically adept, lack many abilities required in real-world engineering situations.” Their vision is that “CDIO is based on a commonly shared premise that engineering graduates should be able to: Conceive — Design — Implement — Operate complex value-added engineering systems in a modern team-based engineering environment to create systems and products” (CDIO website, 2011).

In a comparison of the whole brain and CDIO models, the conceptualization phase in the CDIO model stimulates the conceptual nature of the D quadrant in the whole brain model. The design phase speaks to the logical rational nature of the A quadrant. During the implementation phase the methodical and procedural aspects of the B quadrant are highlighted. The interpersonal and kinaesthetic aspects of the C quadrant are emphasised during the operational phase.

**Interventions**

According to the Hermann Brain Dominance Instrument (HBDI) assessment of all the mining engineering students at UP there is a clear tendency to favour the left hemisphere. In development of interventions, special care is thus taken to not only focus on typical left brain interventions, but also to develop interventions to strengthen students’ abilities in the right hemisphere. All these interventions aim to involve students actively as a whole person and in groups in their field of study. The development of interventions is focused on the following five areas:

**Resources**

Concepts and terminology of the work environment is foreign to most mining engineering student. All the teaching material of the mining modules is therefore designed to enhance the one-dimensional script through inclusion of pictures, illustrations, simulations, reconstructions, animations and video material. An additional databank of resources is also available to introduce students to complex mining concepts. This extends the left-hemispherical nature of pure content to the more visual and conceptual nature of the right-hemisphere in the brain profile. It supports students in the conceptual and operational phases of the CDIO framework.

**Professional Skills**

Management and leadership principles, as well as other people skills are critical components in the curriculum. Several selection procedures are used to identify differences in the personalities and group tendency relationships of individual students. These results are utilized in the professional development, mentoring and coaching. These interventions
develop the interpersonal and expressive aspects of the C quadrant in the brain profile and support students in all the phases of the CDIO, but specifically in the operational phase.

**Support**

Mentoring and coaching of individuals, as well as teams, support identification of academic problem areas and also develop collaboration skills. The “caring nature” (as an addition to a sound technical knowledge base) of the mining engineering practitioner is thus developed. All these aspects provide students with the opportunity to develop in those areas lacking, as identified in the professional development.

**Communication**

An increase in student numbers created communication problems (amongst others due to the multi-language environment and second language tuition). Various mechanisms are utilized to enhance communication.

**Teaching**

The department’s teaching approach changed considerably to incorporate larger groups in terms of the whole brain, active, collaborative and CDIO teaching and learning strategies. The cognitive level of engagement also increased significantly. These strategies culminate in a holistic teaching and learning environment where key elements of the strategy can be monitored on a group and individual basis to make the learning experience much more rewarding and worthwhile for lecturers and students alike.

**Conclusion**

Due to the complexities associated with mining engineering as a career various different approaches have to be integrated into a holistic approach to mining education. This gave birth to the concept of “real time mining engineering education for real time mining engineers”. Recognition for this approach was received from the Mining Advisory board, the Minerals Education Trust Fund, as well as through a Laureate Education Innovation Award at UP.

**References**


We would like to thank the Engineering Council of South Africa (ECSA) for their generous sponsorship of the event.