Thinking and practising curriculum: A new first year course in chemical engineering at UCT

Jennifer M. Case[1], Harro von Blottnitz, Duncan M. Fraser, Hilton Heydenrych, Jochen Petersen

Department of Chemical Engineering, University of Cape Town, South Africa.

[1] jenni.case@uct.ac.za

The engineering curriculum has been a subject of debate since the inception of engineering programmes at universities, with an ongoing and dynamic tension between industry and academic views on 'what matters'. This paper focuses on the practicalities of the implementation of a new curriculum design that is located within contemporary global moves towards a more appropriate and relevant undergraduate curriculum.

As part of a larger overall curriculum renewal process, the Department of Chemical Engineering at the University of Cape Town in 2013 launched a new first year course in chemical engineering. The new curriculum design is centred on two key objectives: to improve the quality of student learning in the programme and to bring the programme up to date with contemporary developments in the profession, including stressing the centrality of sustainable development. To achieve these ends a number of key changes are envisaged to the core curriculum. A 'project-centred' curriculum design has been adopted where there is a strand of project work running throughout the curriculum alongside theory, with explicit reinforcement of the theory by the project work.

The core chemical engineering part of the curriculum comprises one full year course per year for the first three years of the programme. In order to accommodate a broad range of student backgrounds and facilitate academic success, vacation 'bootcamps' are introduced to allow for extra time on task for those who need it. Furthermore, sustainable development is introduced up front in the first year of the course. The new first year course is functioning as a trial of the viability of this new design. This paper outlines key design features of the course and provides preliminary evidence on their suitability and feasibility. Student feedback shows that students find this both an interesting and challenging course.

Introduction

The engineering curriculum has been a subject of debate since the inception of engineering programmes at universities (Prieto et al. 2009). It could be expected that the university and industry would have slightly different departure points for thinking about what should be in the curriculum and how it should be structured. Within the university, engineering programmes obtained legitimacy by allying themselves with science, developing research programmes in engineering science and developing curricula which have a strong basis in scientific knowledge (Noble 1977). From the perspective of industry looking in, the focus has always been on what the engineering graduate can actually 'do'. Historically, it has been argued that academic interests have generally had the upper hand, with a reasonable accommodation of the interests of industry and the professions (Harwood 2006). This uneasy truce does, however, explain the persistence of a certain level of handwringing about the engineering curriculum.

Contemporary discussions in engineering education have recast this historical tension within the current concerns in higher education more generally about 'global employability', 'graduate attributes', etc. (for example, Froyd & Ohland 2005; Rompelman & De Graaff 2006). And thus, the topic of engineering curriculum remains high on the agenda, even though, in real terms, these curricula, at least across the Anglophone world, are not much changed from those half a century ago. Part of this relates to the natural conservatism of the university – something that we should justly expect of an institution charged with protecting society's store of valuable knowledge. On the other hand, many commentators feel that the 21st century offers challenges of the kind and magnitude for which 20th century solutions are not appropriate. With regard to engineering education, these can be seen to encompass challenges both in the arena of student learning and within the domain of the profession itself.

Thus the focus of this paper is on the possibilities and opportunities for sensible change in engineering curriculum – both protecting the status and value of these qualifications while also responding adequately to contemporary challenges. The paper focuses on current work to renew the undergraduate curriculum at the University of Cape Town, in particular on the 2013 rollout of a new first year course in chemical engineering, designed to trial a new course structure that can be carried into the other years of this programme. This paper outlines key design features of the course and provides preliminary evidence on their suitability and feasibility.

Curriculum reform in chemical engineering at the University of Cape Town (UCT)

The chemical engineering programme at UCT started in the 1950s and has had periodic changes made to it, most recently in 1995 with the establishment of a first year engineering course and the inclusion of design courses in second year. The programme takes in approximately 130 new students each year, with a wide demographic spread comprising a majority of black South African students. The most recent complete throughput analyses show that approximately two thirds of the intake graduate in the programme, and only half of these graduates complete in the specified four years for this programme.

The Department has been conducting education research on student learning in its undergraduate programme over nearly two decades, and, together with other evidence the following shortcomings of the current curriculum have been noted:

a. Many students struggle to make the transition from high school to university. There is a foundation programme which caters for a small minority who come from very disadvantaged schooling (Academic Support Programme for Engineering at Cape Town – ASPECT), but this leaves in the mainstream the majority, many of whom also experience considerable difficulty.

b. The curriculum is overloaded and this militates against high quality learning in the programme.

c. There is a lack of coherence and integration in key areas across the programme, most notably in mathematics, computing, teamwork and communication.

d. Students do not get adequate exposure to the chemical engineering profession during their studies, and this also is somewhat out of touch with the ways in which the profession is changing, in particular a significantly increased emphasis on sustainable development.

e. There are no opportunities for specialisation and limited choice of electives in the current programme.

Building then on these perspectives and informed by the latest international scholarship on engineering education, the new curriculum is centred on the following two interrelated objectives:

1. Improve the quality of student learning in the programme in order to increase the throughput of successful graduates, as well as the quality of those graduates.

2. Increase relevance of the curriculum to contemporary and future foci in chemical engineering (including research-led teaching and sustainable development).

In designing a new curriculum we have been guided by international developments at top chemical engineering institutions, most notably University of Sydney, University of Queensland, and Imperial College. The new programme will remain a four year bachelor's programme, meeting the requirements of the Engineering Council of South Africa (ECSA). The core curriculum is sufficiently unchanged that this will not need to register as a new programme. However, in structure and in modes of teaching and learning it is significantly different to the current curriculum.

The programme will involve a larger proportion of elective courses than previously, with the introduction of science electives and a refocusing on the humanities elective space, including a compulsory language course. This paper, however, focuses on the core chemical engineering part of the curriculum. Full year courses in each year of the programme are envisaged, allowing for better integration of material across topics, and the inclusion of a sustained strand of project work. The first year course which has been rolled out in 2013 contains the course design features that are envisaged for the second and third year core courses, and thus the evaluation of this trial course is an important stage in the overall curriculum reform process.

Key curriculum design features of the new core chemical engineering year courses

Project-centred curriculum

A logical response to the critique that engineering graduates are insufficiently prepared for engineering work is to suggest an increased role for project work throughout the programme. Engineering students have always done project work at the final year level in the so-called 'capstone' courses (Jawitz et al. 2002). At the other end of the curriculum, first year courses in engineering have been around for at least two decades now, and many of these have substantial project components. The debate now centres on curriculum models which carry project work through all the years of the programme. The most prominent labels for these new curriculum models are those under the banners of *problem-based* and *project-based* learning (Perrenet et al. 2000; Mills & Treagust 2003). Problem-based learning (PBL) originated in medical education and in its pure form it rests on an assumption that students will learn best in 'authentic' learning contexts where they are tackling real world problems and locating the necessary knowledge as they need it. Project-centred learning typically refers to course modes where students are required to apply the knowledge that they have been taught; the focus here is on the application of knowledge through the problem. Problem-based learning is a much more radical move where knowledge is only accessed as and when needed by the project. PBL suggests that contextual problems can provide the structure for a journey through engineering knowledge. Working from a perspective focusing on professional knowledge, we have argued that introducing PBL as an organising structure for curriculum is a risky move. In potentially compromising the disciplinary logic, this apparently progressive move may further compound the hurdles that students face in navigating the engineering curriculum (Case 2011). We have thus designed our curriculum as 'project-centred' where there is a strand of project work running throughout the curriculum but theory is still explicitly taught alongside project work.

A major emphasis throughout what we have thus termed the 'practice' strand of the curriculum will be on design and analysis, as useful foci for understanding the discipline and the profession (Duncan & Reimer 1998). It is important to note here that although very few of our graduates will end up focusing on design in their careers, we see a focus on design as a useful teaching tool for making sense of the discipline. It is also a key site where we demonstrate and explore some of the future directions for the profession. The practice strand will also involve practical activities including laboratory investigations. Another important area that will be integrated into the practice strand is communication, from writing and presentations to teamwork and technical drawing. These will no longer be taught in separate courses, but integrated into the practice strand, as well as being carefully integrated across the years. Another key aspect of the practice strand is the explicit learning of a range of 'tools,' such as spreadsheeting and flowsheeting, and the assessment of skills in these tools through 'competency tests' in which a high level of proficiency will be required.

Focus on conceptual understanding in the theory space

It is a well-established finding across much of science and engineering that curricula are overloaded (Sparkes 1991). As knowledge progresses, more gets pushed into the curriculum but seldom are topics removed. Another well-established finding is that students may well pass examinations in these subjects but this does not mean they really grasp the key concepts at hand (Fensham et al. 1994). It not a massive causal leap to see that there is at least some relation between these two aspects of the status quo. A well-known mantra suggests: 'Cover less, uncover more'. To this end, we are structuring our new curriculum with a clear and logical progression of key ideas. Year courses will be structured into modules which will mean that within the course at a given time students will be only focusing on one knowledge area.

In the new curriculum, formative assessment will be used to promote conceptual understanding, with the inclusion of mastery tests in each module. These are set to test the absolute basics and students are required to achieve 80% in the mastery test (opportunities are given for rewriting the test). These test marks do not actually count towards the final course mark; they are simply hurdles that need to be mastered at the basic level in the course. Class tests and a final examination will continue to be the summative means whereby student performance in the theory strand will be assessed.

A crucial aspect of the curriculum is that the clear distinction between the 'practice' and the 'theory' strands means that appropriate teaching and assessment can be used for these very different aspects of engineering knowledge. Of course the curriculum will require that students carry over knowledge from one arena to the other, but, importantly, the practice space will not need to be, as it presently is, a further area where the focus is on testing conceptual understanding. The tight assessment in the theory space, including mastery tests, will mean that project assessment can be free to operate in a more open-ended mode, with use of team-based project deliverables, and so on.

Strategies to facilitate success for a wide range of students

As noted earlier, one of the key drivers for this programme of curriculum renewal is to improve the quality of student learning. The design of strands of project and theory running alongside each other described above is a first key aspect for making more legible to students the logic of the profession and providing opportunities to build knowledge in a sustained manner over the four years of the programme. The year course structure also allows appropriate time for students to obtain feedback and to be able to modify their approaches as the year progresses. Moreover, with integrated assessment decisions at the end of each year course which consider student performance across a range of assessment events, there is a better opportunity to properly judge whether a student has met the appropriate requirements for progression on to the next stage of the curriculum. Crucially, students will not be 'straddling' years, carrying courses from one year into part of the next year. This current arrangement, long touted as the 'flexible curriculum', actually has the effect of a pronounced lack of coherence for students who land up in this position.

A further strategy will be employed to maximise the opportunities for success within the year course for the broadest range of students. Winter and summer 'bootcamps' take in students who have not met the required assessment markers, and give them extra structured tutorial-type interventions, to catch up and consolidate the material from the semester. These have already been trialled in 2012 and have run with great success under the able leadership of top postgraduate students appointed as assistant lecturers for the duration of the bootcamp.

This aspect of the curriculum design responds logically to the observation that at UCT we currently use a very small portion of the available year for teaching. Most of our students do not have the opportunity to work or travel extensively during the vacation and thus that is essentially wasted time for them. This arrangement will allow for better use of the year for students. This particular approach also allows us to keep most of the cohort who started studying together to stay together through their studies. Thus our efforts at building an effective learning community will not be undermined by students straddling years.

Sustainable development as a departure point for chemical engineering

A second key driver for this curriculum renewal programme, as noted earlier, is aimed at keeping the curriculum up to date. The chemical engineering profession is changing rapidly as the world faces unprecedented challenges in the areas of resource and energy provision. Sustainable development has emerged as an increasing focus, as seen most notably in recent policy documents from the UK-based Institution of Chemical Engineers (IChemE). The IChemE are quite explicit in their position that undergraduate curricula need to change to develop graduates that have an in-depth understanding of sustainable development (IChemE 2007).

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. Our existing curriculum only introduces sustainable development at the fourth year level, in line with many other curricula where the more professional aspects of engineering work get introduced in this capstone year. However, there are many drawbacks to this design, and thus the new first year course introduces sustainable development up front as a guiding concept for evaluating chemical engineering design and processes.

Structure of the new first year course

Working towards the implementation of the revised four-year programme, a new first year course was introduced in 2013, incorporating the key design features described above. The course is structured into four six-week modules, each with the generic structure showed below in Figure 1.

Week 1

Period	Day	Monday	Tuesday	Wednesday	Thursday	Friday
1 - 2	08:00-09:45					
3	10:00-10:45	Theory 1		Theory 3	Exercises 3	Theory 4
4 - Meridian	11:00-13:45					
6	14:00-14:45		Exercises 1			Exercises 4
7	15:00-15:45		Theory 2			Theory 5
8	16:00-16:45		Exercises 2			Exercises 5

Week 4

Period	Day	Monday	Tuesday	Wednesday	Thursday	Friday
1 - 2	08:00-09:45					
3	10:00-10:45	Mastery Test		Theory 10	Exercises 10	Practice 6
4 - Meridian	11:00-13:45					
6	14:00-14:45		Practice 5			Practice 7
7	15:00-15:45		Project/Prac			Project/Prac
8	16:00-16:45		Project/Prac			Project/Prac

Week 2

Period	Day	Monday	Tuesday	Wednesday	Thursday	Friday
1 - 2	08:00-09:45					
3	10:00-10:45	Mastery Test		Exercises 7	Theory 8	Exercises 8
4 - Meridian	11:00-13:45					
6	14:00-14:45		Theory 6			Practice 1
7	15:00-15:45		Exercises 6			Project/Prac
8	16:00-16:45		Theory 7			Project/Prac

Week 5

Period	Day	Monday	Tuesday	Wednesday	Thursday	Friday
1 - 2	08:00-09:45					
3	10:00-10:45	Mastery Make-up		Theory 11	Exercises 11	Practice 9
4 - Meridian	11:00-13:45					
6	14:00-14:45		Practice 8			Class Test
7	15:00-15:45		Project/Prac			Class Test
8	16:00-16:45		Project/Prac			Class Test

Week 3

Period	Day	Monday	Tuesday	Wednesday	Thursday	Friday
1 - 2	08:00-09:45					
3	10:00-10:45	Mastery Make-up		Theory 9	Exercises 9	Practice 3
4 - Meridian	11:00-13:45					
6	14:00-14:45		Practice 2			Practice 4
7	15:00-15:45		Project/Prac			Project/Prac
8	16:00-16:45		Project/Prac			Project/Prac

Week 6

Period	Day	Monday	Tuesday	Wednesday	Thursday	Friday
1 - 2	08:00-09:45					
3	10:00-10:45	Practice 10		Theory 12	Exercises 12	Practice 12
4 - Meridian	11:00-13:45					
6	14:00-14:45		Practice 11			Project
7	15:00-15:45		Project/Prac			Project
8	16:00-16:45		Project/Prac			Project

Figure 1. Generic module structure

A number of features are evident in Figure 1. The 'theory' space is coloured in blue and it can be noted that lecture sessions alternate with 'exercises' which can be considered to be mini-tutorials. The first two weeks of the module are heavy on theory and the project space (coloured in orange) commences at the end of this period. Termed 'practice' are the lecture plenary inputs which students need in order to tackle the project work. In the projects, students work in groups but tackle both individual and group tasks. Using tutors we have managed to get a fast turnaround on feedback on the project tasks such that students can use this feedback going forward in the project. Mastery tests are signalled in purple and it can be seen that retests are scheduled into the module structure. Some of these tests are conceptual mastery tests and others are skills competency tests. There is also a mastery test in typing (30 wpm with 90% accuracy) and students get an opportunity in each module to attempt this test (which can also be practised online at any time).

Within this course, the focus on sustainable development comes in with a set of lectures and exercises around the theme of 'Natural Foundations' in order to build in students an adequate grasp of the limits and functioning of the planet's resources. At a course level this has involved more engagement with text and an inclusion of more open-ended debate into the course. This has to some extent raised the cognitive demand of the first year course, which historically was more located in relatively simple calculations. Sustainable development topics are also reflected in the choice of project assignments.

This course is part of a pilot at UCT where all students are required to own laptops for use in class (UCT has made a special allocation to assist Financial Aid students in this regard). The course is thus also trialling a range of innovative uses of computer technology to assist in teaching and learning, including more intensive use of the course website, a completely paper free course, the use of online software with 'clicker' type applications and project work in the class venue which uses computer applications such as Excel and Word.

An important aspect of the delivery of this course in the mode just described is the workload and contributions of the different members of the teaching team. Two lecturers (the first two authors) are each teaching two of the four modules. There is a team of eight tutors plus a senior tutor who manages their workload and co-ordinates the marking. Intermediate project submissions are marked by the tutors and moderated by the lecturer (which enables the fast turnaround time for these submissions). Tutors are also present in all the lectures and exercise sessions.

The team also includes a retired academic (the third author) who is developing the new course material required, for both the practicals run in each module and the projects. The practicals and the projects have been designed carefully so that they do indeed fulfil the objective of reinforcing the theory being learned in each module (which is one of the most challenging aspects of developing this kind of curriculum).

In view of all that we were doing in this course, we needed a course venue that could accommodate the shift from lectures to exercises and team project work, as well as intensive use of laptops. We were grateful to have been allocated a venue in which we can have one row free between every two rows of students, to allow for access to the students during the exercise sessions.

Preliminary evaluation of the course after the first six weeks

A number of types of evidence have been collected in order to provide an important early assessment of the course. Some of this is informal and includes the ongoing reflections of the lecturer during the first module (the first author), the content of daily conversations with students in the class, and connections with the postgraduate tutors on the course. In addition, somewhat more formally, students were invited almost on a weekly basis to provide brief written feedback. In the first four weeks this involved a short text answer to the prompts to describe ‘My teaching. Your learning. The laptops’. At the end of the six weeks students took part in a mid-semester course evaluation which comprised quantitative survey questions but also gave opportunity for open-ended comment. Of the 131 students in the class, the numbers of students who participated in each of these feedback opportunities is summarised in Table 1 below.

Table 1. Student feedback responses

Timing	Week 1 & 2	Week 3 & 4	Evaluation (Week 6)
N	65	79	38

It should be noted that much of the data from Week 2 was accidentally deleted. For this reason the responses across Weeks 1 and 2 was grouped together, similarly for Weeks 3 and 4. The numbers represented here are of students who participated in either or both of these i.e. they represent the total number of unique individuals responding (not the number of responses). A majority of students who did respond gave responses in both weeks. Week 6 attracted a smaller and slightly different group of students (about 20% of these students who completed the mid-semester evaluation had not previously given feedback).

The analysis which follows aimed at identifying themes that were dominant across the responses at a particular stage.

During the first two weeks there were many comments from students saying that they were enjoying the course; many noted the interactive teaching style.

> Of all the lectures I have attended the past week. I would say that CHE1005W was definitely my favourite. I learnt so much and well compared to the other teachers/lectures, I say that mrs Jenny was the best of them all. I didn't feel scared and out of place.

Many students made comments along the lines that they found the course interesting and challenging.

> For the first time I'm forced to think out of the box. I have realised that I can never be satisfied with what I know. I have learnt a lot over the past few days.

> …modern approach, encourages us to find out what's going on in the world around us ourselves.

At the same time, a number of them noted that the pace was fast. There were many comments from students wanting more guidance on what they needed to actually 'study', on what would be in the tests and examination. Here is an exemplar of this concern:

> I am a bit concerned as to what we will be required to learn for exams and tests. Will we need to know all the processes in detail or are these just simply examples we are using to practice designing different processes? Could you try and distinguish between what is interesting additional information or examples and what we will actually need to learn.

They wanted the lecturer to more carefully go through the correct answers for the problems that had been tackled in the 'exercises' session; they were not satisfied to have simply received confirmation from the tutors on whether their work was correct or not.

With regard to the laptops, many comments indicated that this was a massive adjustment. Most commonly it was noted that the laptop was heavy and they were not sure it was really necessary.

> I feel the laptops are a bit too heavy to carry around. I have never had to use a laptop this often. I'm not very computer literate. I prefer the old fashioned pen and paper. However it's a matter of time before I get used to it. It's like learning to walk.

There were some concerns around the security issues of carrying a laptop around. Some of them were trying to take notes on the laptop during lectures and they weren't sure that this was appropriate. They struggled with the limited desk space in the lecture venue. There were, however, a few positive comments on having a laptop from students who were finding that they liked the ease of accessing information on the internet.

It was in the area of the laptops that the greatest shift was noted in student comments from the first two weeks to the next two. Students noted that they were getting used to the laptop, they were becoming more proficient at using it, and they were liking it!

> Laptops: gets cooler every week. Am able to google things as I have questions.

This shift is not all that surprising since the project had started and this required them to locate information on the internet, write short summaries, and draw diagrams. There had also been sustained use of the laptop during lectures, with one clicker-type question per lecture and ongoing use of all other aspects of delivering material and information through the course website. There remained a few comments on the heaviness of carrying the laptop around and a rainy day sparked extra concerns on how to avoid getting your laptop wet. And the issue of battery life appeared on the agenda – now that the laptops needed to be used across a two hour project session – and there were only four plug points in the whole lecture venue.

With the course in general, the comments on the interactivity and the challenge continued. Now there were also many more comments that the pace had increased (further) and that there were now lots of tasks that had to be completed.

> It's been very busy, really feeling the reality of university life now. Next week is just as hectic.

A notable shift in the comments here was that many students actually responded to the request to write about ‘My learning’ and had evaluative comments to make on what they were grasping and what they were still grappling with, as seen in this comment:

> The use of laptops has really really helped in this weekly session. However, I still find have to adjust my way of learning towards this course. So far I have realised that it doesn't require only going through the text book and grasping the concepts, rather it requires intensive application of the concepts learned in class.

The mid-semester evaluation had a very different mode and a lower response rate and thus the comments are not easily comparable. Nonetheless, in the quantitative questions a considerable majority indicated that they were very happy with their course experience across a range of dimensions (organisation / learning activities / tutor preparation / lecturer’s teaching ability and approachability). A notable outlier (not uncommon in our undergraduate courses though) was the area of tutor feedback. There were only 10 written comments given in this evaluation and so not too much can be made from these. However, in these comments some students noted that they were not happy that tutors ‘gave different answers’ (although this might be expected in a project type context) and were also not happy with feedback on their marked submissions. The marking of the individual project tasks had indeed been very demanding on tutors both in the complexity of the task and the time for turnaround. The moderation of 1 in 5 tasks by the lecturer had at least highlighted areas for improvement of tutor marking, and the lecturer’s impression was that the quality of marking had increased dramatically across the four tasks that were marked by tutors. This evaluation had also been completed just after the class test at the end of the module and so it was not surprising that there were also comments at this point that they wanted more clear guidance on what exactly they needed to study (Only 100/131 students obtained more than 50% for this class test).

Conclusion

The rollout of a new first year course has been an important trialling exercise for the overall curriculum plan. With this course carrying the essential structure that is intended for the core chemical engineering courses in the second and third years, many important lessons are emerging. The key response that has come both from the written evaluations and across informal reports and conversations is that the students are finding this course both interesting and challenging – a number of students describe this as their *most* interesting and *most* challenging course. This is of course precisely what one might hope for in the central core course in a professional programme.

Many aspects of the student experience in the first six weeks of this course seem acute descriptors of the initial, almost bewildering, experience of transitioning from school to university. In school there is a clear set of notes or a textbook which describes exactly what you need to know – nothing more than this can be asked in the final school examination. Particularly with the inclusion of topics in natural foundations, the new first year course has opened things up considerably. This aspect of the course expects students to look critically at the outcomes of the modern resource-based economy. Even in the area of mass balances there are key conceptual ideas but these need to be ready to be applied to new contexts. The inclusion of a project strand in the very first module provided an additional challenge but also further opportunities for engagement and stimulation.

The laptop project is a fascinating extra addition to this new course. Student feedback over the first four weeks plotted the quick shift from not knowing what to do with this tool to starting to find it useful and also rewarding. Early indications are that this will quickly become an essential part of how we deliver our curriculum.

In summary then, these are the early implementation days of a process of curriculum overhaul.

This course will continue to be closely tracked as the year progresses. The expectation is that students should become increasingly comfortable as they move through further modules which have the same structure and type of expectations although they incrementally build new knowledge. That said, to provide challenge is something that a university programme should not shy away from. The early engagement and interest is an encouraging sign.

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