Trade-offs in curriculum design: Implementation of an integrated curriculum in chemical engineering

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***Abstract*— This Innovative Practice Full Paper reports on perceptions of a curriculum reform innovation in an undergraduate engineering program in chemical engineering at a South African university. A key feature of this program is an integrated curriculum design, which involves a coherent development of theoretical topics alongside closely related project work. This design was chosen in alignment with the core objectives which were to improve the quality of student learning in the program and to increase the relevance of the curriculum to contemporary developments in the profession. The study took place during the year in which the final year of the new curriculum for the four-year program was implemented. Both lecturers and teaching assistants involved in delivering the new curriculum, and final year students who had been the first cohort through the curriculum were surveyed in an open-ended questionnaire. The study goes beyond a traditional evaluation design to be able to research in-depth differing perceptions of the new curriculum. The discussion focuses on the implicit trade-offs when moving to a more integrated curriculum design. The analysis also focuses on the inherent immediate challenges of implementing a substantial change to curriculum, and how this is perceived by both academics and students.**

Keywords— curriculum reform, student learning, student experiences, student success

I. Introduction

Debate on curriculum reform in engineering education has a long history and the vigor of this debate continues to the present [1]. A central pivot for the debate is the tension between the more theoretical and practical elements of the curriculum [2]. With the introduction of the reformed ABET criteria, and their international impact through the Washington Accord, there has been a move towards the practical, with an increased focus on the professional skills that engineers require on entering the workplace [3].

It has been noted though that even compliance with these new outcomes-based criteria has been largely accomplished through revisions of existing curricula, rather than the more substantial reform programs that might have been envisaged [4]. Furthermore, there has been substantial innovation at a first year level [5] but limited work especially in the middle two years of the four year curriculum [6, 7]. This is not surprising; more broadly it has been noted how discussions on curriculum might play a more symbolic than practical role in education reform [8, 9].

This paper reports then on a relatively rare occurrence in engineering education, that of a whole-sale curriculum reform, where an entire program was revised substantially across its four years. The overall process from initial deliberations through to implementation took place over nearly a decade, and the first cohort graduated from the new curriculum in 2017 [10].

Much of the reform was along the lines of the revised ABET outcomes, with an increase on project work across all four years, and substantially more assessment devoted to the outcomes of this work. This aspect of the curriculum design also allowed for the program to meet its objective of including more context of contemporary professional relevance, especially in the context of sustainable development, and with a developing world focus for most of the projects [11]. Fundamentally, this project-centered design [12] required a more integrated [13] curriculum structure across all four years.

An additional key aspect of this curriculum reform project relates to important work in South African engineering education as it works with a racially diverse student population from a range of education backgrounds. The curriculum reform in this program built on more than two decades of work in pedagogical, course and institutional reform, to increase the access and success for a diverse group of students [14].

A central issue for course and curriculum reformers in engineering education relates to how to gauge the impact of a reform. In the US engineering education community, quantitative experimental designs have tended to be favored [15], yet in the education and social science research fields more broadly there are substantial critiques on the limitations of trying to 'measure' impact in this way [16, 17]. Much contemporary thinking in education research looks to investigate more deeply how students experience a course/curriculum context and to see how this relates to the intended curriculum [18-20]. The present study reports on a novel methodology in this regard, which surveyed lecturers, teaching assistants, and students, on their experiences of the revised curriculum.

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The findings of this study go well beyond 'proving' that the curriculum reform has 'worked'. Rather they point to the complexity of any reform, which inherently involves trade-offs. It is shown here how this revised curriculum did achieve its intentions of supporting student success across a diverse group of students, but that this was (as one might expect) perceived in different ways by these students. The study also provides an important snapshot of the challenges involved in educational reform [21], in that it specifically invited people involved to comment on these, some of which were related more to the transition than the actual design of the new curriculum.

II. BACKGROUND CONTEXT

The chemical engineering program at this university started in the 1950s and has had periodic changes made to it, most recently (prior to the current revision) in 1995 with the establishment of a first year engineering course and the inclusion of design courses in second year. The program takes in approximately 130 new students each year, with a wide demographic spread and the majority black South African students (noting that, within the South African context, Black African, Indian and Coloured students are collectively referred to as black South Africans).

There are two sub-programs available: a four-year (Mainstream) program and a five-year (ASPECT) program. Approximately 20% of the students are in the ASPECT program, which they select to change to typically during their first year. Because this study is focused on the first cohort coming through the new curriculum, it is based on the experiences of the Mainstream 2014 incoming cohort who graduated during the year in which the study took place. Table I shows the demographic breakdown of this cohort.

TABLE I. DEMOGRAPHIC BREAKDOWN OF 2014 MAINSTREAM COHORT IN CHEMICAL ENGINEERING PROGRAM

Demographic group		No. of students
South African	Black African	24
	Indian	20
	Coloured	12
	White/Unknown	33
International		22
Total		111

The Department had been conducting education research on student learning in its undergraduate program over nearly two decades, and, together with other evidence, the following shortcomings of the previous curriculum had been noted.

1. Many students struggled to make the transition from high school to university. While the ASPECT program catered for a minority who came from very disadvantaged schooling, the majority in the Mainstream also experienced some degree of difficulty.
2. The curriculum was overloaded and this militated against high quality learning in the program.
3. There was a lack of coherence and integration in key areas across the program, most notably in mathematics, computing, teamwork and communication.
4. In cases where students experienced difficulty, the large number of modular courses also contributed to the lack of coherence, and particular if they failed one or more of these courses, in which case they would straddle years and peer-cohorts.
5. Students did not get adequate exposure to the chemical engineering profession during their studies.
6. The curriculum was somewhat out of touch with the ways in which the profession is changing, in particular the increased emphasis on sustainable development.
7. There were no opportunities for specialisation and limited choice of electives in the program.

III. THE NEW CURRICULUM

Building then on these perspectives and informed by 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 program to increase throughput of successful graduates, as well as to improve 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, the Department was guided by international developments at top chemical engineering institutions, most notably University of Sydney, University of Queensland, and Imperial College [7, 12, 22]. Further important input on content coverage came from the IChemE Roadmap project [23] and the European Federation of Chemical Engineering (EFCE) Working Party on Education (WPE) [24].

Key features include a sustained offering of project work throughout the curriculum, the use of mastery assessment, and the use of vacation time for supported preparation for supplementary examinations, building towards year-by-year progression through the program. Further structural details on the new curriculum are given in the Appendix at the end of this paper.

IV. THE PRESENT STUDY

Throughout this process of curriculum reform, the Department had engaged closely in scholarly activities to inform this process. Firstly, the curriculum design built on nearly 20 years of engineering education research in the Department. Secondly, the roll-out of the new first year took place over two years to allow for research on the revised curriculum structure [10]. Thirdly, as the curriculum rolled out into the second and third year, evaluation work was conducted in order to inform minor iterations on the curriculum design. The present study builds on all these insights and focuses specifically on the experiences of the first cohort as they reached final year.

The starting point for our assessment of the new curriculum was to consider student performance, and particularly graduate throughputs, for the new curriculum. These are reported briefly at the outset of the Findings section below.

However, a curriculum cannot only be evaluated on student performance, even though that is surprisingly common in the engineering education literature. In short, you do not need to change a curriculum to change performance outcomes, you just need to change the assessment system. But if you are really interested in learning outcomes more broadly, you need to do more than an analysis of student grades, and build in a broader investigation of student experience of the curriculum. Based on our long and sustained program of engineering education research, we knew that traditional quantitative measures of student experience would be unlikely to offer the kind of insights we needed to judge the impact of this new curriculum [25]. It must be emphasized here that we were not simply aiming to 'prove' that the new curriculum 'worked' or even 'met its objectives' – such studies are possible but easily miss the inherent complexities in student experiences and the subtle disjunctures between intended and implemented curricula that are a key feature of any educational context [26]. In line with our ongoing approach to engineering education reform in this Department, we are particularly interested to investigate course contexts which are based on best-practice, not only for the instances in which they achieve their ends, but even more importantly on those aspects in which they don't [27].

Leading up to and during the process of curriculum reform we had conducted substantial work based on individual student interviews and focus groups, and for this study we wanted to retain the open-ended qualitative response format, but chose to do this in a survey so as to be able to capture a wider range of responses. We also knew from course evaluation responses over the four years that these students were likely to offer fairly elaborated written responses to such prompts.

At the outset of the survey respondents were informed of the nature of this research project and the way in which the data would be used. We felt it was important to not require students to identify themselves in any way in this survey, and so no demographic features were required. This is also because our substantial engineering education research to date has shown that race is less a causal feature for students' experiences than is social and educational background. We were confident that the fullness of students' responses would allow us to identify these background influences.

We therefore opted for a survey methodology, but chose a purely open-ended format with very limited questions, to prompt for expansive responses. Following a preamble detailing the person's role in the curriculum, respondents were asked three main questions:

1. In your view, what are the main features of the new curriculum?
2. What do you see as the main advantages of the new curriculum (from the perspective of students)?
3. What do you see as the main disadvantages of the new curriculum (from the perspective of students)?

Lecturers and teaching assistants were also asked to respond to the second and third questions from their perspective. Finally, students were asked about the experience of being the first cohort in the new curriculum, and faculty and teaching assistants were asked about the way this experience had influenced them professionally.

Only students who had: (a) done the Mainstream program entirely in the new curriculum; and (b) had started the final (fourth) year in 2017 (even if they did not complete the year successfully) were invited to complete the survey. This meant 89 students were invited, including five who had entered as transferee/conversion students. Of these, 47 students completed the survey, a response rate of 53%.

The instructional faculty in the undergraduate department at this university can roughly be divided into four categories: permanent faculty, three-year contract faculty, short-term contract faculty and faculty whose primary departmental role is research. Core courses are mostly taught by the first two groups, while the latter two groups' involvement is largely in the electives and in the capstone design and research courses in the final semester. Because of their long-term membership in the department, most permanent faculty were involved in the development of the new curriculum, with other categories typically less so. Table II shows the survey completion data for the various faculty categories.

TABLE II. SURVEY COMPLETION FOR DIFFERENT FACULTY CATEGORIES

Category	Invited to complete survey	Completed survey
Permanent	13*	7
Three-year contract	5	1
Short-term contract	4	1
Research	8	2
Total	30	11

* The two authors of this paper, both permanent faculty during the development and implementation of the new curriculum, were excluded from the survey.

Although the overall completion rate was 11/30 = 37%, the completion rate for permanent faculty (i.e. those most closely associated with the development and implementation of the new curriculum) was 7/13 = 54%, while there were only one or two responses from each of the other categories. These latter categories of lecturers were less involved in the development and implementation of the curriculum, so we were not too concerned about the lower response rates.

The vast majority of undergraduate teaching assistants in the core-courses, supplementary winter- and summer-school sessions and electives are drawn from the postgraduate population in the department. For this survey, only currently-registered postgraduates who had served as teaching assistants during 2015, 2016 or 2017 were invited to complete the survey. This amounted to a total number of 104 individuals, of whom 19 (i.e. 18%) completed the survey.

The analysis drew on a typical grounded theory methodology using the method of constant comparison to identify common themes [28]. The analysis followed the structure of structure of the survey, in that the first phase worked with responses to the first question referring to what respondents saw as the main features of the new curriculum. This was a significant aspect of the research design, in that rather than ask students to respond to our definition of the new curriculum, we wanted to find out what aspects were most prominent in their experience.

From this first phase of analysis we noted substantial mention of two aspects: project work and the block structure. The comments on project work were largely very positive and are only mentioned briefly here. The more substantial analysis took the responses on the second and third questions regarding advantages and disadvantages, where we were found contrasting perceptions about the impact of the block structure on conceptual learning. This thus became a substantial focus for the analysis presented in this paper. The final stage of analysis looked overall at student perceptions of assessment outcomes, which importantly links back to the quantitative analysis of throughput at the outset of this study.

An important point to emphasize is that qualitative methodologies are not only exploratory, but in fact have significant potential to advance both descriptive accounts but also causal explanations of these [17]. The analysis presented in this paper while grounded should not merely be considered as exploratory. It offers a significant and grounded analysis of the contradictions and trade-offs involved in actual curriculum reform in engineering education.

V. Findings of the Study

A. Analysis of graduation throughputs

Since this paper focuses on the first four-year cohort, the discussion of throughput is limited to minimum-time throughput in the Mainstream program. As can be seen from Table III, even prior to the implementation of the new curriculum, minimum-time throughput had risen from 35% (2000-2004) to approximately 40% (2005-2010) (see Heydenrych & Case, 2015), and then to 55-60% (2011-2013). However, while a similar trend has been seen in the various demographic groups, there have been significant disparities in the throughput rates, with particularly black African South Africans seeing lower throughput rates.

TABLE III. Throughput Data for Mainstream Chemical Engineering Program

Minimum-time throughput (% of original cohort) for Mainstream program

Demographic group		2000-4	2005-9	2010	2011	2012	2013	2014
South African	Black African	14	26	28	38	23	41	67
	Indian	22	31	38	50	67	57	75
	Coloured	34	39	42	45	56	71	58
	White/Unknown	64	61	50	90	68	78	67
International		27	42	39	62	60	65	59
Overall		35	42	39	61	54	62	66

As can be seen from Table III, the overall minimum-time throughput has, for the 2014 cohort, increased slightly from previous cohorts. However, more notable is that for Black African South Africans there has been a large step change increase in throughput. Clearly this, as with all the data for the 2014 cohort, may be a statistical aberration. However, there is evidence – from the tracking of progress of later cohorts – that this increase will be at least partially sustained.

B. Main features of the new curriculum

We have described the main features of the new curriculum as we understand them above (and in the Appendix), but we were interested to see what features stood out for respondents. Doing a thematic qualitative analysis of the open-ended responses that were given to the question: "In your view, what are the main features of the new curriculum?", we identified the following categories:

- Block Structure – those who made reference to the structure of 'blocks' whereby one subject area at a time was dealt with in the whole year courses
- More Project Work – any comment referring to increased emphasis on project work
- More Integration of Theory & Practice – comments that specifically referred to integration of different parts of the curriculum
- Changed Assessment System – references to the range of assessment activities through the course, and how these were used in overall progression decisions
- Inclusion of SHE focus – references to more inclusion of topics in the broad area of Safety, Health and Environment
- More Computing & Related Practice Skills – more emphasis on computing and other skills especially relevant to the project assignments
- More Elective Choice – reference to the introduction of choice in all of 2nd year science electives, in advanced engineering electives, and also in humanities electives

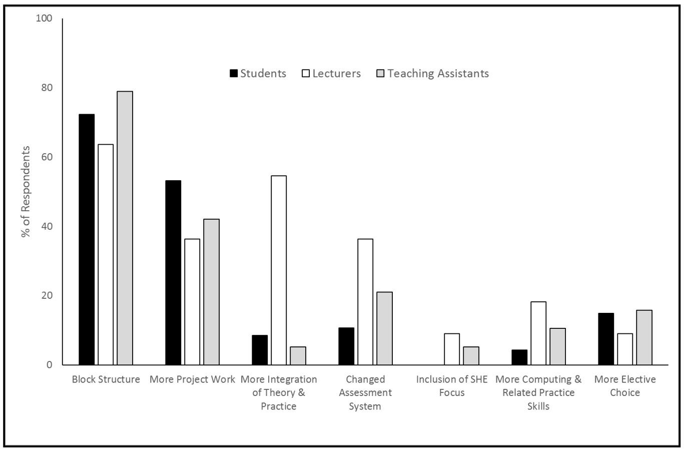

Fig. 1. Frequency of Response Types for Different Groups of Respondents to the Question "What are the Main Features of the New Curriculum?"

As is shown in Figure 1, the block structure was the overwhelmingly visible aspect of the curriculum and mentioned by a strong majority across all groups of respondents. There was also strong mention of project work. References to integration and a changed assessment structure came more from lecturers, and the remaining topics were mentioned only by a minority of respondents.

The analysis proceeded to look at students' responses on advantages and disadvantages of the new curriculum. The topic of project work only appeared as an advantage, and is discussed only briefly below. The block structure, interestingly, appeared as both an advantage and a disadvantage (sometimes by the same individual) and thus gets substantially more treatment in the remainder of this section of the paper.

C. Advantages of increased project work

Of the respondents, 21 of them specifically elaborated on the project work as an advantage of the new curriculum. It was not mentioned as a disadvantage.

A few respondents referred to the way in which project work allowed for the integration of theory and practice, but this was not a major theme. More substantially, both lecturers and students referred to the ways in which the projects built skills that they would need not only for their final year capstone projects, but also for the working world. For example, one of the teaching assistants wrote:

The new curriculum gives a better introduction to what chemical engineering is about and the role chemical engineers play in society. The introduction of project based work is integral to this in my opinion as it introduces them to practical examples. As someone who went through the previous curriculum it is a welcome change.

D. The 'block' structure and perceptions of impact on conceptual learning

As noted above, one of the key drivers for the new curriculum was an intention to improve the quality of learning. The block structure was implemented so that students would only be working in one conceptual area at a particular time. Instead of one class session per day on a topic and a weekly afternoon tutorial, from second year onwards students would spend at least two sessions in the morning and two full afternoons in the week on a particular topic.

There were many responses stating that students felt the block structure helped as they only had to focus on one topic at a time and that this could aid conceptual mastery. There were also many responses that the intensity of the block structure worked against conceptual mastery as there was not enough time to grapple with conceptual challenges. We have given these two categories of responses respectively the shorthand 'Better Learning' and 'Worse Learning'

Significantly, many students gave responses in both these categories, for example in this response from a student to questions 2 and 3:

Main advantages:

Taught one thing at a time instead of learning different material in different courses concurrently ['Better Learning']

Main disadvantages:

Not enough time to consolidate work taught (especially on long days with two morning periods and 3 afternoon periods) - was taught something in the morning and expected to understand before the afternoon lecture that teaches a new thing following from the morning lecture. ['Worse Learning']

[S07]

Figure 2 shows the proportion of respondents mentioning each of these points, and importantly shows those who gave both (apparently contradictory) responses. The responses coded as those indicating that the block structure helped their learning ('Better Learning') were defined as those with references to 'understanding', 'conceptual understanding', 'concepts' etc. It is interesting that so many students in this program use these terms to talk about their learning.

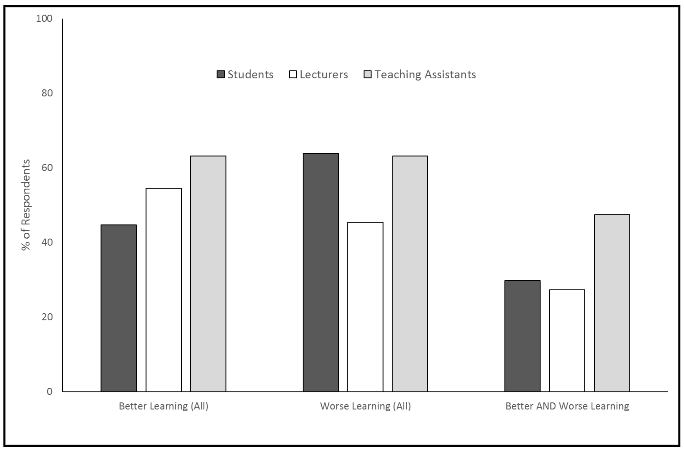

Fig. 2. Frequency of Comments on Learning Outcomes for Different Groups of Respondents

Given the scope of this paper, the analysis from this point will focus on the student perceptions,but noting that the contradictions to be outlined here were also noted by lecturers and teaching assistants.

In terms of how the curriculum structure had aided their. learning, many made reference to focus, attention and concentration, for example:

focusing on one material at a time is helpful in keeping the attention and focus on it [S43]

focus on one concept at a time more intensely [S36]

In explaining how the block structure aided understanding, there were references to the assessment structure including the mastery tests, which some students felt aided the development of fundamental concepts (as was intended). Some respondents also mentioned the way the block structure moved from 'theory' to project work, and how the latter aided in reinforcing understanding (again as was intended):

The introduction of the project work afterwards was much appreciated, as it helped in cementing the understanding of the different concepts in that topic. [S29]

As noted above, a key issue is that students felt that conceptual understanding was important in this program. One student wrote:

Mastery and competency tests are a good way of assessing the conceptual understanding of the material. I mean in the absence of these, students might still do well in the test or exam without necessarily having a quick and pragmatic understanding of the block content, tests and exams being mostly based on tutorials. In a sense, if at some point in their life, the chemical engineer forgot all the equations, that conceptual and *pragmatic understanding well acquired in the mastery and competency tests would always prevail. [S42]*

An interesting point was made by one student, that this structure might be particularly beneficial for some students:

The new course allows students to focus on one specific concept at a time which I think is beneficial for someone like me who cannot cope with learning multiple/different concepts at the same time [S37]

However, as noted at the outset of this section, there were also many responses that felt that while it was good to focus on one conceptual area at a time, that the curriculum structure did not have enough time for this to take place, and that overall this compromised on the possibilities for conceptual understanding, what we termed above with the category 'Worse Learning'.

One aspect is the inevitable trade-off when moving to a more modular structure, which is that students have to move through a whole new topic in a relatively short space of days. Many students made comments that not only was this exhausting, but that it worked against their mastery of the concepts:

Having a whole day of lectures, theoretically, allows students to focus on the work and ask questions in a ordered, consecutive manner. Unfortunately, owing to the long days [specifically in CHE3005W] this was not achieved practically as the long hours is exhausting for the student and the lecturers. Additionally, it was difficult to not really know anything about the topic at 10h00 and then by 18h00 essentially finishing two weeks worth of information. If one did not understand a concept or if one needs time to reflect on the work to fully understand it, meridian was the only time to do so to ensure that one understood everything. [S47]

Another student felt the issue was that different students would master material at different paces, and that the block structure exacerbated this impact:

Sitting in one class for the entire day is a lose-lose situation for everyone. If you are a student who grasps the concept quickly, you get bored and lose focus because you understand already. If you are a student who doesn't understand, you end up falling exponentially behind because the lectures move on regardless of if you've grasped the concept or not. There is no time to let the topic sink in - if you misunderstand a lecture in the morning, the entire day is lost on you [S41]

Within this perspective, there were many comments that students had had to focus on passing the course at the expense of understanding:

One of the major regrets that I have is that due to the intensity and limited time of the block nature forced me to compromise on understanding and push me to parrot learn methods of solutions to pass test, exams etc. Something that I prided myself was the understanding of what however as I progressed from first year to third year i lost that (due to the reasoning in my previous sentence) and will always regret it. [S38]

There were also comments that the concurrent traditional curriculum allowed not only the additional time to master material, but also for potential cross influences between subjects:

Some courses related and have aspects that enable one to expand their understanding when they run concurrently giving rise to many "Ahhaa" moments but when courses are consecutively done this prohibits students from making connections and when a lecturer in e.g. Block 8 is referring to Block 4, it is difficult to recall and hence diminishing the thorough understanding of engineering concepts and the ability to relate concepts.[S30]

The comment was also made by a few respondents that the conceptual areas for some blocks (e.g. Thermodynamics) might need more time than others.

Thus, in contradiction to the intention and the perception that the block structure allowed for better conceptual understanding because of handling one topic at a time, the view was also put forward by many that the fast pacing of individual blocks mitigated against understanding, and while students might have passed the overall assessments that their understanding was poor. A number of students expressed personal regret over this.

This leads into a broader debate also reflected in the survey responses on the overall assessment outcomes achieved by the first cohort of students in the new curriculum. As noted above, the overall throughputs to graduation were higher than with previous cohorts, and students offered many comment on this even though the survey did not explicitly prompt them to do so.

E. Overall assessment outcomes

As shown above, early indications are that the new curriculum meets its intentions of better facilitating student progression through the curriculum. Although a fear was still stated by a fair number of staff and students that failing a full year course would be consequential, most students especially recognized that progression was more likely in this curriculum.

There were thus many comments from students specifically (18/47 students) around a perception that it was 'easier to pass' in the new curriculum. For many students, this was not necessarily that the assessments were 'easier' but that the whole structure with multiple assessment points, clear organization, and a holistic assessment decisions allowed for more students to achieve passing results. Here is one example of such a response, note that the reference here is to the 'average student':

The new curriculum makes it better for the average student to successfully complete the challenging chemical engineering degree in four years, compared to the previous curriculum. It does this by making the curriculum more structured with room for students to mitigate failure by bootcamps, second attempts at mastery/competency tests and having a more defined lay out of the curriculum. [S06]

Some students, rather than referring to a generalized 'average student', offered personal comment on how they feel they had benefited from this new curriculum and assessment system; here is one student expounding on the bootcamps.

The bootcamp is super awesome. I know alot of people dread bootcamp, but being the bootcamp baby that I am I truly appreciate the effort put into bootcamps. I feel like it allowed me to engage more with the work without any additional pressure. [S25]

There were quite a few references that the assessment system allowed one to 'redeem' oneself in that a poor initial assessment outcome could be mitigated by a good result in a later assessment:

The fact that the courses are all one course. Unlike in the previous years, with this type of learning you can easily make a mistake in one or two courses and redeem yourself later on. So in essence it allows me as a person to reflect and try to push harder instead of learning when I already have to repeat courses. [S25]

There was further comment, some personal as here, on the overall assessment outcomes for the year course:

The structure of this new curriculum allows for students to finish the degree in 4 years. This is possible as some students are able to pass the overall course without the need to pass every block. From my own experiences I obtained an average in the 40-49% for one of my blocks and still managed to pass the year because of my other blocks and my project work. [S08]

Interestingly, there were a few students who felt that the experience of being borderline had been very stressful and they had worried a lot about the possibility of failing the whole course:

failing other parts of a whole year course means failing the whole course, this is not fair, If I have a weakness in reactor design I should repeat the reactor design section only. [S34]

I think paying for the whole year course is financially straining especially to those students who fail one or two blocks and then have to pay for the entire course again. Many students feel this is very unreasonable. [S31]

One student commenting on this mentioned that he/she had some concerns about their level of mastery of the weak block:

I also have got through a whole year course having failed mass transfer because other courses pulled up my average. But now I still don't have knowledge on the subject. [S24]

This concern was taken up strongly by a group of [9] students who also felt it was 'easier to pass' in the new curriculum, but felt strongly that some students who were passing who should not be passing. Some of these comments referred to the system just noted that one weaker block could be mitigated by performance in others, but mostly comments centered especially on the assessment of groupwork in the course:

The fact that students can pass CHE courses based on the group work element, and can thus do minimal work yet still get through projects based on the work of other students in the group. [S45]

Some of these comments were quite pointed:

The large amount of group work and significant amount of "safety nets" lowers the standard of people making it into the higher years. For this reason, virtually everyone in class knows key "problematic" students who you are downright unfortunate to get in your group as it is common knowledge that you'll have to "carry" them. [S01]

Overall these students voiced concerns about the reputation of the degree:

The fact that those students then also passed the course reduces my value as a graduate [from this institution]. [S02]

Some referenced more intrinsic purposes of the degree and the kind of engineers it was producing:

The curriculum almost feels like it's a professional degree for people who will work as engineers and neglects the fact that some of us studied engineering for the love of science and not to get a job or anything along those lines. [S44]

VI. Discussion and Conclusion

This paper has presented an analysis of key themes emerging in a study of faculty and student perceptions of a curriculum reform. One of the key objectives of the new curriculum was to facilitate better learning, and to this end the 'block structure' was implemented, whereby new theoretical topics were dealt with intensively, one at a time, not in parallel as in traditional curricula. The study has shown that the block structure was certainly recognized by respondents as being a dominant feature of the curriculum reform, but opinions were mixed on whether this facilitated the better learning that it had intended.

Building on its intentions to foster better learning, the new curriculum had also intended to foster academic success and progression through the program. And, as shown in the quantitative analyses of throughput, this intention was achieved overall, with a step change in minimum time graduation for Black African students. The analysis of survey responses showed that many students felt that it was now 'easier to pass' and a subset of these felt concerned that some of the students who were passing should not be passing.

The study points to the complexity of actually implementing curriculum reform, rather than just talking about it as is the more common practice. Beyond any simplistic statements around the difficulty of change, what this study shows is the very real challenge of changing structures to support learning. With limited time in the academic year, a move to a blocked structure, while theoretically good, does result in an intensity which can work counter to its intentions. And changing an assessment structure which gives more opportunities for assessment, and a holistic progression decision, while desirable for even intrinsic reasons of removing unnecessary hurdles to progression, will have varying perceptions in the student body, especially those who typically achieve well.

Appendix: Details of New Curriculum

The new program continues to meet the requirements and outcomes of the Engineering Council of South Africa– a signatory to the Washington Accord – but with a substantially different structure to the previous program. The new curriculum has three components:

1. Core Chemical Engineering
2. Core Science: Mathematics, Chemistry, Physics, Statistics

3. Electives: Basic Science, Advanced Chemical Engineering, Humanities (including a language elective), Free

For each of first to third years, the core-courses in Chemical Engineering comprise theory and practice running alongside each other in one whole-year course. The fourth year remains relatively unchanged apart from a reduction in the core content (with Control moving to third year) and a corresponding increase in the elective space. "Practice" comprises project-work in areas of design, as well as laboratory-based practicals and industrial exposure. The core-courses run through the year in three- or six-week "blocks". The first two-thirds of each block is theory intensive (alongside an appropriate laboratory-based practical), with lectures and tutorials regularly interspersed in a one-to-one ratio. The final one-third of each block is dedicated to project-work related to the block theory, to ensure integration between theory and practice.

Project-work also incorporates flowsheeting & equipment heuristics, environment & economics, health & safety, teamwork, technical communication, computing and drawing. Each of these are seen as strands that run through (and are built up) across the whole curriculum. For each strand, an overall strand-convener provides the necessary content lectures and ensures coherence and progression over the four years. It should be noted that dedicated drawing, computing and communication courses (which were all present in the previous curriculum) have been discarded in favour of the requisite skills and knowledge being taught, applied and assessed in the project/strand space.

It should also be noted that, in the second- and third-year courses, each block has a dedicated set of teaching assistants who attend lectures, assist with tutorials and provide support for the project-work and, in addition to these formal contact-sessions, are available for daily student-consultation sessions. For pragmatic reasons, there are also specialized teaching assistants for laboratory-practicals and computing over the second and third years.

The assessment for the courses comprises:

- Theory: class tests for each block; mid-year tests or end-of-year exams for each semester. This is all individual assessment and has a 60-70% weighting. There are also basic Mastery tests for each block, which require high passing-threshold scores but can be repeated.
- Projects: project reports and/or oral presentations. These have a 22-26% weighting and, while they are largely group-based, there are individual components in some cases. In addition, the second- and third-year courses have an oral examination based on the project work, which has a 10% weighting. There are also individual Competency tests where necessary, to ensure that requisite skills-levels are attained within particular strands (e.g. computing, oral presentation, drawing).
- Practicals: practical reports and/or oral presentations. These have a 4-8% weighting – they are all group-submissions in the first year but are equally split between group- and individual-submissions in the second and third years.

The weightings are given as ranges above, since they vary slightly from one year/course to the next. Overall, each year has a 70-80% weighting to individual- and a 20-30% weighting to group-based assessment. Students switch into new groups at least once per semester.

The core Science in the program comprises the previous courses in first and second year Engineering Mathematics, the first-year Chemistry course, and a semester course in Physics (focusing on mechanics). A semester course in Statistics has been added to the core program, at the expense of a semester course in Physics (focusing on electricity and electromagnetism).

The elective space in the program has been enlarged. Second-year Chemistry, which was previously compulsory, has become an elective alongside alternative routes into Biological Sciences and Geology/Mineralogy. The course offerings in elective Chemical Engineering, building on current research foci in the Department, have been doubled, and allow students to select either "broad" or "deep" options. With regard to electives in Humanities, a compulsory language elective has been introduced, requiring students to do a semester course in a language with which they are not familiar. The liberal arts elective has been focused into a set of options which deal with the social world and thus offer students some background for thinking about the impact of engineering activity on society. There is also a Free elective, allowing the students to take any course of their choice.

Three key strategies have been incorporated in the core-courses to facilitate student success and progression in the program:

1. As noted previously, daily (or even more frequent) tutorials, basic Mastery tests (repeated if necessary) in each block, project- and practical-work to help deepen theoretical knowledge, and a class test at the end of each block, help students stay on top of their work throughout the year.
2. Students who have not met the expected performance at the end of each semester use a portion of the vacation to attempt to master the work: a winter school in mid-year and a summer school at the end of the year provide preparation for supplementary examinations.
3. Year-based (and thus holistic) assessment decisions involve careful evaluation of student performance across all assessments during the year. The large year courses also ensure that, at least within core Chemical Engineering courses, students proceed in a cohort (or join a new cohort for a whole year), facilitating the development of peer-support systems.

This new curriculum is delivered with the existing academic staff complement. Additional teaching assistants are budgeted for to support the teaching during the vacation time.

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