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Design of an extended engineering curriculum to increase retention and equity

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Introduction

Engineers provide the backbone for economic development and infrastructure provision in a society. The dearth of engineers in South Africa is hampering its ability to meet both its internal social development needs and to compete globally. Poor throughput rates in engineering degree programs are exacerbating the problem. Of the 2006 entering cohort of engineering students nationally only 23% completed their degrees in the regulation time of four years, and 41% completed after five years[1]. Of black[a] students, only 9% completed in four years and 22% in five years. There are thus both social and economic imperatives for improving retention and equity in engineering programmes.

Although it has been 21 years since a democratic government was installed in South Africa following the end of apartheid, great inequities in the schooling available to different racial groups within the population still exist. While segregation is no longer law, most black people still live in poor, all-black communities, in which schools are typically staffed by teachers with inadequate subject matter knowledge, particularly in mathematics and science. Furthermore, most black students are the first generation in their families to attend university, and therefore their families cannot prepare them to meet the demands of university life. An additional challenge for most black students is that English, the medium of instruction, is usually their second or third language.

While black students face particular challenges, the education system as a whole is not adequately equipping students, black and white, to cope with the demands of university. Over the past 20 years there have been serial changes to the national curricula, while little attention has been paid to up-skilling teachers. Add to this an ever-increasing emphasis on high-stakes testing and pass rates and the result is an increased focus on drilling students to pass the tests, with little or no focus on developing conceptual understanding or cognitive capacity. For future engineers this is a recipe for disaster, literally.

Changing the quality of schooling is a long-term project, one that lies outside the scope of most academics' activities. It is therefore vital that universities find ways to help students who have the intellectual capacity and motivation to do so to overcome their often inadequate prior educational experiences and succeed in their university programmes and later professional lives. For South Africa, this is the only hope of supplying the country's need for enough competent engineers within a reasonable time frame. In this paper we describe the design features of a planned five-year engineering degree program and show how it has contributed to an increase in the one-year retention rates both in engineering as a whole and for black students, thus addressing the dual challenges of increasing retention and equity.

Context

The University of Pretoria is a large urban university of nearly 50 000 students, approximately 5000 of whom are enrolled in nine undergraduate engineering programs, which, according to government prescriptions, are meant to be completed in four years. As indicated above, only a small minority of students actually do complete engineering degrees in four years. A policy of the government since the end of apartheid in 1994 has been to

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[a] "Black" is sometimes used to mean anyone who is not white, including people of mixed race and of Indian descent. In this paper we will use "black" to refer to ethnic Africans, nearly all of whom are first language speakers of an African language.

increase the number of students in higher education. However, given the weak preparation of many students for university study referred to above, completion rates have remained low[2]. From 2006 onwards government's recognition of this problem, particularly in fields that rely on strong mathematics and science backgrounds, led to the provision of additional funding for extended degree programs provided that a stipulated amount of additional support in the form of extra, credit-bearing courses was coherently integrated into the curriculum.

From 1994 to 2009 the School of Engineering offered an extended degree program designed to take five years to complete to students that did not meet the normal entry requirements, but it did not include additional courses (and therefore did not qualify for extra government funding). In this program level 100 courses were spread out over two years and voluntary tutorials were offered in some of the courses.

In 2009 the first author was hired to manage the 5-year program. Soon after her arrival she requested university data to conduct an analysis of the completion rates for students on the program. The data showed that the program was not having the desired effect on the success of underprepared students, especially black students. For the 2003 entering cohort of students, only 26% of white and 8% of black students completed their degrees in the expected 5 years. For black students, even after seven years the completion rate was only 38%. Given the need to redress the inequities which blacks in South Africa experienced under apartheid, as well as the fact that 80% of South Africa's population is black, increasing the success rate of aspiring black engineering students is essential. It was thus decided to design a new 5-year degree program, one that would qualify for the additional funding the government had made available.

Another event that took place in 2009 was the entry into universities across the country of the first group of students who had taken a new school-leaving examination, the National Senior Certificate, which was based on a new national curriculum. In this paper we use student data from 2009 as the baseline for our intervention since it represents the last year of the old 5-year program and the first year of students entering with the new school-leaving qualification. The new extended degree program, described in the next section, was offered for the first time in 2010, and is called the Engineering Augmented Degree program (ENGAGE).

Program design

Design principles

In the early to mid-1990s the first author had run a successful year-long Science Foundation Program (SFP) for underprepared students that preceded the first year of a degree[3]. That program was designed to provide a phased transition from where the students were in terms of content knowledge, cognitive skills and metacognitive skills to where they needed to be to succeed in science-based university programs. The transition was phased in terms of pace of work, quantity of work, required background knowledge, level of difficulty and support provided. Many aspects of the SFP were deemed to still be relevant for underprepared engineering students in the late 2000s, given that they were based on sound cognitive science and educational psychology on the one hand and that the academic profile of underprepared students had not improved during that period. However, pre-degree, non-credit-bearing courses no longer qualified for government funding. All support had to be credit-bearing and integrated into the curriculum. On the other hand, the School of Engineering did not want the mainstream curricula to be tampered with. The challenge was to design a curriculum that would successfully meet the students' needs, government requirements and School of Engineering prescriptions.

In the light of these constraints, five design principles were identified that informed the structure of the program, namely:

1. Students should be explicitly 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.

The transition from high school to university is increasingly acknowledged as challenging for many students, as evidenced by the rise of "first year experience" programs and "first year seminars", international first year experience conferences (see, for example, the European First Year Experience 2015, www.uib.no/en/efye_2015), centers such as the National Resource Center for First Year Experience and Students in Transition (www.sc.edu/fye), and an international journal on the first year experience (https://fyhejournal.com/index). In South Africa about a third of students drop out or fail their first year of university study[4].

Some of the things first year students typically struggle with are: choosing a career direction, managing their time, mastering academic skills such as effective study methods and academic reading and writing, assessing their own understanding of their work, coping with the fast pace and high volume of work, being actively engaged and finding a peer support group in first year classes that are often very large.

In order to make the transition from high school to university more manageable for underprepared students, the ENGAGE program requires students to spend long hours working, what we call a high workload, but initially the amount of new content that is covered in that time, what we call volume of work, is low. This allows students to build up intellectual stamina by having to apply their minds to academic tasks for many more hours a week than they are used to, but not overloading them with so much new content that they cannot keep up.

The transition from high school to university is also facilitated in the ENGAGE program by providing a considerable amount of structured support in the first year, less support in the second year, and no formal support after that (though there is a lighter credit load in the third year than for mainstream students).

The fifth design principle arises from the well-known educational principle that people learn better when new knowledge can be related to what they already know. In the words of Ausubel[5], "The most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly."

Operationalization of the design principles

The five design principles were operationalized by creating additional courses to accompany all 100 level mainstream courses, spreading the 100 and 200 level courses over three years and postponing the introduction of engineering courses from year 1 to year 2. In year 1 students also take two semester-long Professional Orientation courses in which academic and life skills are developed within an engineering context. All courses are credit-bearing, so ENGAGE students earn a larger number of credits than mainstream, 4-year program students. The additional courses are not remedial, but are developmental in that their objectives are to develop students' conceptual understanding, background knowledge and problem-solving skills. Professional Orientation is also developmental in that it helps students develop a range of skills needed to succeed in engineering.

As far as the career direction aspect of making the transition to university is concerned, ENGAGE students have already chosen to study engineering, so career choice is not an issue, but there are several program features that are designed to help students identify with the profession. First, the two Professional Orientation courses utilize a project-based approach and engineering contexts within which to develop academic and life skills. Second, five projects in the first two years make explicit use of the internationally developed Conceive-Design-Implement-Operate (CDIO) approach to engineering education (http://www.cdio.org), three in Professional Orientation, one in Additional Physics and one in Additional Mechanics. In addition to providing a simulated engineering context, these projects help students learn to work in teams, an essential skill for future engineers. Third, students receive a student guide at the beginning of the program in which the outcomes of an engineering degree are included, as stipulated by the Engineering Council of South Africa[6]. These outcomes are referred to repeatedly in Professional Orientation.

In order to help students develop their time management skills and ability to assess their own understanding there are weekly assignments in every course, which are handed in, graded and handed back. There are also a range of other formative assessment tasks of varying duration. Engagement with the subject matter, peers and teachers is encouraged by the course structure. For the additional courses only one period per week utilizes a lecture format. The other three periods per week are activity-based and take place in groups of about 50 with an instructor and a senior student tutor. Professional Orientation meets six times a week and is entirely activity-based.

The groups of about 50 students are structured according to engineering discipline, so, for example, the chemical engineering students will be in one group, or maybe split across two groups at the most, while the mechanical engineering students will be in a different group. These groups function as peer support groups, and enable students to feel a sense of identity and belonging, something that is difficult to achieve in the mainstream lectures of 500 students or more, which ENGAGE students also attend.

In the design of the ENGAGE program, a distinction is made between workload and volume of work. "Workload" is used to mean the amount of time that an "average" ENGAGE student would be expected to spend on course-related activities, including class time, study time, assignments, tests and examinations. "Volume of work" is the amount of new material that is included in a course. A weakness in the design of the previous extended degree programme was the assumption that the way to help underprepared students was to lower the volume of work in the first two years by lowering the workload, i.e., to spread one year's course load over two years. This has the effect of delaying the shock of a full workload to the third year. The ENGAGE programme is designed to scaffold students' ability to cope with an increasing volume of work by keeping the workload roughly constant and reducing the support, in the form of developmental courses, over time. Figure 1 shows the number of developmental and mainstream courses taken by ENGAGE students during each semester of each year of the program. The thickness of the block indicates the relative credit value of the course.

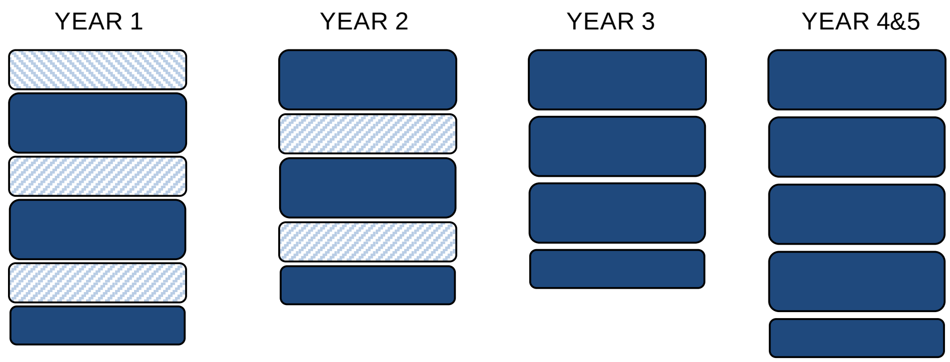

Figure 1: Mainstream (dark blocks) and developmental (light blocks) courses in each year of the ENGAGE program.

The additional courses add to the students' workload, but they do not add to the volume of work as they do not involve new subject matter. Instead, these courses require students to engage more deeply with the subject matter that is addressed in the mainstream courses. This includes deepening students' understanding of background knowledge that mainstream instructors assume is in place.

In Year 1, students only encounter the familiar subjects of mathematics, physics and chemistry. Year 2 adds an extra dimension of challenge as students take engineering courses for the first time, albeit at level 100, such as mechanics and engineering drawing (graphical communication). In Year 3 there are no support courses but the volume of work is a little less than for mainstream students in Year 2 as ENGAGE students take some of their level 200 mathematics in Year 2. In Years 4 and 5 the program is identical to the mainstream program in Years 3 and 4. From Year 1 ENGAGE students are in the same classes as students on a 4-year program for all of their mainstream courses.

Program operation

The ENGAGE program is coherent. The structure, contact hours and format are similar for all additional courses. All ENGAGE courses follow a similar format for assessing students. Attendance is mandatory, and students who fail to attend several classes in any subject receive a warning. All ENGAGE teachers, i.e. those who teach the first and second year additional courses and Professional Orientation, have regular meetings throughout the year. This enables them to share good practices and challenges, as well as identifying opportunities to build on what students are learning in other courses. Certain activities are formally included in the curricula of two or more courses that enable students to transfer what they learn from one course to another, thereby deepening their understanding. For example, in Year 1 students learn about centre of mass in Additional Physics and apply this concept in a CDIO activity in which they build a "skyscraper" out of extruded polystyrene and pencils[7]. In Year 2 in Additional Mechanics they revisit the Skyscraper activity and perform a more detailed analysis of centre of mass for the structure.

Teachers of the additional courses also meet regularly with teachers of mainstream courses to identify aspects of mainstream courses that students typically struggle with, as well as keeping appraised of what is being covered and when. This enables ENGAGE teachers to design their curricula in a way that provides appropriate scaffolding for students' learning.

Individual student performance is monitored, and, when necessary, students are referred to a counsellor or adviser for support.

Results

A survey was administered to all ENGAGE students at the end of their first year on the program. The response rates from those who completed the year were 80% (209/260) for 2010 and 67% (238/354) for 2011[b]. Table 1 shows the results from the generic questions related to the program as a whole. (Other questions were subject-specific.)

Table 1: Percentage (number) of first year ENGAGE students who strongly agreed or agreed with the statements on the end of year evaluations in 2010 (N=209) and 2011 (N=238)

Question	2010 % (Number)	2011 % (Number)
Being an ENGAGE student has helped me make the transition from school to university	79 (180)	81 (192)
I felt there was someone I could go to if I had academic problems during the year	80 (183)	70 (166)
I got the support I needed this year	79 (181)	84 (200)
I kept up to date with my work this semester	77 (175)	78 (187)
I coped with the workload this semester	80 (183)	82 (196)
I learned useful life skills in ENGAGE this semester	66 (151)	67 (161)
After this semester I still want to be an engineer	90 (206)	92 (222)

Most of the respondents indicated that ENGAGE helped them to make the transition from high school to university, to get support, to keep up and to cope. Moreover, a large majority still wanted to be engineers.

Table 2 provides a summary of responses to a questionnaire administered to the 2010 cohort of ENGAGE students at the end of their second year in 2011. The response rate was 58% (N=115/198).

Table 2: Percentage (number) of second year ENGAGE students in Year 2 in 2011 who strongly agreed or agreed with the statements on the end of year evaluation

Question	% (Number)
Being an ENGAGE student helped me cope in my 2nd year at university.	72 (83)

[b] The higher participation rate in 2010 was because student submissions were monitored and follow up was done with students who did not submit the questionnaire. This was not done in 2011.

I felt there was someone I could go to if I had academic problems during the semester.	65 (75)
I felt there was someone I could go to if I had personal problems during the semester.	39 (45)
I got the support I needed this semester.	71 (82)
I kept up to date with my work this semester.	79 (91)
I coped with the workload this semester.	82 (94)
The skills and knowledge I gained in ENGAGE up to now are helping me this year.	65 (75)
After this semester, I still want to be an engineer.	97 (112)

It is interesting to note that most of the respondents felt that ENGAGE helped them cope in their second year, not only their first year, and that almost all of them still want to be engineers. However, most of them did not feel that there was someone they could go to for personal problems.

One of the questions on the questionnaire was, "Please write one or two paragraphs to describe your experiences as an ENGAGE student this year." Selected responses from first year ENGAGE students are shown below from male and female as well as black and white students. "JPO" is the code used to designate ENGAGE courses. (In the quotes below "module" means "course").

> My experience as an Engage student was really worthwhile and enjoyable the additional module i.e JPO modules helped me to understand the contents [of] my major modules. It also helped me to interact with my peers inside and outside the school/work premises [black female]

> My experience as an ENGAGE student was very fruitful. The additional modules were very helpful and they made for foundation which I think will have long lasting benefits….I have no regrets for having enrolled in the ENGAGE programme when I look at how I have grown academically and personally. [black male]

> For me it was fun doing many projects, group work and [I] learned how to think and reason in the right way. The ENGAGE program helped me a lot with the "bridge" from school to university. [white female]

> I got the support I want, it helped me to make transition from school to university. The project we did simply showed me what to expect in engineering world because I thought when you're [an] engineer, you only need to solve mathematics and science. [black male]

> This year has been a great learning curve for myself. With the help of additional subjects overcoming learning obstacles has been easier. [white male]

Data on the one-year retention rates for both 4-year and 5-year program students are shown in Table 3, using 2009, the year before ENGAGE began, as the baseline. Since the students in the 5-year program were less well-prepared for university than those in the 4-year (mainstream) program it is interesting to compare the retention rates of the two groups. The table shows that after two years of running ENGAGE, more students were placed in the 5-year program, one-year retention figures increased for both 4 and 5 year program students and there was an increase in both the number and percentage of students retained in engineering overall.

Table 3: One-year retention figures for students in 4 and 5 year programs

	Initially registered			Still registered one year later		
Year of entry	**4-year degree**	**5-year degree**	**TOTAL**	**4-year degree**	**5-year degree**	**TOTAL**
2009	847	208	1055	645 (76.2%)	101 (48.6%)	746 (70.7%)
2010	794	288	1082	632 (79.7%)	188 (75.4%)	820 (78.5%)
2011	691	366	1057	600 (86.8%)	278 (76.0%)	878 (83.1%)

Table 4 shows that the one-year retention rate for black students was nearly the same as for the whole student cohort.

Table 4: One-year retention figures for black students in 4 and 5 year programs

	Initially registered			Still registered one year later		
Year of entry	**4-year degree**	**5-year degree**	**TOTAL**	**4-year degree**	**5-year degree**	**TOTAL**
2009	204	104	308	143 (70.1%)	55 (52.9%)	198 (64.3%)
2010	202	103	305	148 (73.3%)	80 (77.6%)	228 (74.8%)
2011	167	156	323	141 (84.4%)	125 (80.1%)	266 (82.4%)

In education nothing is static and so changes in performance can never be attributed to a single cause. Nonetheless, the ENGAGE program constituted a major change to the program offerings in engineering in 2010.

In 2011 there was another change. As a result of the poorer performance of entering students in 2009 who had obtained the new National Senior Certificate compared with students that had taken the previous school-leaving examinations, it was decided to raise the selection criteria for entrance into both the 4-year and the 5-year (ENGAGE) engineering programs. Additional information to guide selection and placement decisions was available in the form of the newly-introduced National Benchmark Tests (http://www.nbt.ac.za), developed by Higher Education South Africa, which universities could choose to require students to take. Thus the 2011 results were undoubtedly affected by better selection and placement decisions, in addition to the ENGAGE program.

Conclusion

Although longitudinal data on student retention and completion still need to be analysed, one-year retention figures, combined with qualitative evaluation data, suggest that the ENGAGE program is having a positive influence on both student retention and equity. This can be explained, at least in part, by the inclusion of a number of practices that research on learning and on student success have shown to be effective. Many of these practices are successful because they promote student engagement, a key factor in student success. According to Kuh *et al*[8],

> "…student engagement has two key components that contribute to student success. The first is the amount of time and effort students put into their studies and other activities that lead to the experiences and outcomes that constitute student success. The second is the ways the institution allocates resources and organizes learning opportunities and services to induce students to participate in and benefit from such activities."

Through their work over many years, Kuh[9] and colleagues have identified a number of "high-impact practices" that research shows lead to increased student success. Of these high impact practices, the following are embedded in the ENGAGE program: first-year seminars and experiences, common intellectual experiences, learning communities and collaborative assignments and projects. The two Professional Orientation courses achieve many of the same goals as first year seminars at other universities, such as helping students acquire a range of academic and life skills needed for student success and developing critical thinking in an inter-disciplinary context (at least in the sense that all engineering specialisations are included and social and environmental issues are raised). Since ENGAGE students take the same set of courses in year 1, there are ample opportunities for common intellectual experiences. In addition, students have a number of assignments and projects that they work on collaboratively.

ENGAGE students can also be considered to be part of learning communities. In learning communities students take several classes together and the teachers of the classes communicate with one another to make links across their subjects. According to Tinto[10] in learning communities, "Students not only pursue a common body of knowledge but also share the experience of gaining that knowledge together." As the name suggests, learning communities help students feel a sense of belonging, which is important in countering the isolation, even alienation, that first year students may feel in large classes. This is even more important for students from under-represented demographic groups. Learning communities are a useful way to foster the academic and social integration that Tinto[11] posits as key to student persistence. The design of the ENGAGE program, in which students are grouped according to engineering discipline and meet in classes of about 50, creates learning communities. It is worth noting that these groupings cross both gender and racial boundaries to foster students' identities as future engineers. Informal conversations with ENGAGE students in their senior years suggest that the students gravitate towards other ENGAGE students when group work or study groups are required, regardless of their race or gender, rather than to students on the 4-year program who share demographic characteristics with them.

Another important feature of the ENGAGE program is that all aspects of it are formal, credit-bearing, timetabled and required. Many efforts to support students who are deemed to be at risk fail because they are voluntary. Student support staff often lament that the students who most need support are the ones who do not avail themselves of the support on offer. However, one of the contributory factors to students' being "at risk" is their poor self-regulation, which often manifests as a failure to seek appropriate support. In the ENGAGE program appropriate support is built into the program. Support is embedded in the classroom experience, the only place where students are required to be, and, in the case of the majority of students who commute to campus, possibly the only place where they interact with their peers and instructors. Moreover, the classroom is central to student learning, as Tinto makes clear:

> Student success, however defined and measured, necessarily arises in the classroom, one course at a time, over time. Lest one forget, the object of student persistence is not merely that students complete their programs of study, but that they learn while doing so. Learning is the object of our work, persistence is merely a vehicle to achieve that end. Though learning can occur in a variety of places

outside the classroom, it is in the classroom experience that is central to student learning in their field of study.[12]

Finally, ENGAGE promotes student identification with their chosen profession of engineering from the start, which has been shown to increase student persistence[13]. This is evident in the very high proportion of students who say they still want to engineers at the end of their first and second years.

In this paper we have described a carefully designed extended degree program that is showing great promise as a means of increasing both student retention and equity in engineering programs at our university. In the future we plan to analyse longitudinal data to investigate how many students stay in the program and eventually graduate.

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[1] These figures were accessed from the Higher Education Management Information System of the Department of Higher Education and Training, to which all universities are required to submit data annually.

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