A review of three approaches to determining students' capabilities for studying engineering

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Abstract: *The staff at a number of Australian engineering schools are using a range of aptitude tests to: (a) grow student numbers in engineering programs by facilitating the entry of students who have an aptitude to study engineering but do not meet entry requirements;(b) identify 'at risk' students and provide them with counselling and remedial classes to facilitate a successful transition to university; (c) empower students with self-awareness and learning skills; and/or (d) identify the factors that lead to success in first year engineering studies. Some examples of the tests currently being used include the Australian Technology Network Engineering Selection Test (ATNEST); the Preparing for First Year Engineering (PFFYE) competency test; and the Student Learning Profiles online test. This paper reviews these three approaches currently being used in Australian universities and describes the methods used to deploy the tests, and the experiences gained from implementing the tests. The paper discusses the outcomes of the tests and explores the feasibility of synthesising the best features of the existing tests to develop a single multi-purpose test. Engineering schools could then be able to select and deploy the test, or components of the test, to meet their requirements.*

Introduction

Australia continues to face a critical shortage of engineers and engineering associates. Engineers Australia (2008) reported that "in the five years between 2001 and 2006, the number of Australia's engineers in the profession decreased by around 6500, with more engineers having left the workforce than having joined it" (p. 6). At that time it was estimated that by the end of the decade from 2001 to 2011, more than 70,000 engineers would have retired from the profession, while 55,000 migrant engineers would join the workforce. Kaspura (2011) reported that over the last decade the demand for engineering staff at all levels rose by 52% to 124,400, (compared to 20% for the overall Australian economy), while the number of engineering program completions added 94,495 to the workforce. Over the same period the number of degree graduates per year remained relatively static at between 6500 and 8500 per year. It is therefore critical that the all sectors of the industry help to grow the numbers of students undertaking engineering studies (at all levels) and the number of graduates through enhanced retention of students who commence engineering.

Growing the pool of commencing engineering students

King (2008) noted that one of the strategies to grow the commencing pool was the need to increase the public understanding of engineering and the work of engineers, particularly in schools. King, Dowling, and Godfrey (2011) identified five strategies that could be used to increase the number of commencing students in engineering degree programs. One involves growing engineering's share of the total commencing student undergraduate students, including increasing the percentages of female and Indigenous students in undergraduate engineering programs. Another considers increasing the number of entry pathways for students who are ineligible for standard entry. This paper describes some of the initiatives that engineering schools are currently using to facilitate pathways and grow student numbers into engineering programs.

Retention

From a retention perspective, the attrition of first year undergraduate students remains a major concern (Godfrey & King, 2011). Research evidence indicates that students enter university with expectations about the learning experience which influence their approach to study and, in turn, their retention (Krause, Hartley, James, & McInnis, 2005). Students are often poorly informed about the nature of their coursework (Krause et al., 2005) and inappropriate discipline choice is an important determinant of student withdrawal (Yorke & Longden, 2008). Many research projects have sought to identify factors that affect student attrition, with a substantial focus on factors such as homesickness or financial pressures (Long, Ferrier, & Heagney, 2006). Recent American research indicates that many freshman engineering students become discouraged when they perceive their performance to be inferior to their peers; they switch majors or drop out of college entirely (Hutchison-Green, 2008). Similarly, a longitudinal study by Matusovich, Streveler, and Miller (2010) found that a “sense of self” is fundamental to students’ choice and persistence in their engineering degree programs. Thus, educators must help first year students experience early success, gain confidence in their self-efficacy, and bridge the gap between their expectations and those of the institution.

Research aims

Three of the recommendations in the Australian National Engineering Taskforce (ANET, 2011) executive summary report addressed the need for Higher Education (HE) institutions (both universities and Vocational Education and Training [VET] institutions) to work more closely to improve the graduation rates of VET graduates in engineering degrees by enhancing articulation pathways and support mechanisms for transitioning students (King et al., 2011). Two of those recommendations (ANET, 2011, p. 10) are relevant to this discussion:

1. “1B: Engineering degree providers in higher education should diagnose any gaps in the knowledge and skills of students admitted on the basis of a VET award early in their program and provide appropriate academic support to address such gaps.
2. 1C: Providers of engineering programs in both the VET and HE sectors should enhance the provision of transitional support, such as mentoring and career advice, to students who have the potential to embark on a VET-HE pathway.”

It is posited that engineering schools should apply the two strategies incorporated in these recommendations to all commencing students rather than just VET graduates. Thus, engineering schools should routinely diagnose any gaps in the knowledge and skills of commencing students, and they should offer transitional support, such as mentoring and careers advice, to all commencing students.

This paper reviews three approaches currently being used to discern how students’ interests, knowledge, skills and experiences might influence their decision to choose engineering, and if those factors can be used to predict academic success in first year. This review was conducted as part of a recently successful ALTC grant application to fund the development of an Engineering Career Appraisal Tool (EngCAT). Thus the aim is to identify the capabilities, knowledge, traits and skill sets that typically are suited to engineering studies and, in turn, develop strategies that provide appropriate support mechanisms to facilitate student retention and progression.

If these predictors of success can been identified, then engineering schools will be able to:

- Use the outcomes to make informed decisions about entry standards and alternative entry pathways, and develop appropriate support mechanisms for the different groups of transitioning students.
- Develop strategies to attract those students who demonstrate a good fit to the engineering discipline, assist them to make an informed career choice, and enable them to experience success in first year and beyond.
- Develop pathways for prospective students who have an interest in studying engineering, but who have significant gaps in their knowledge, skills or capabilities. Examples of existing pathways are: bridging programs, foundation degrees, and articulation pathways from the VET sector.

Approach

This research draws on the knowledge and experiences of senior academic staff from three engineering schools that have used testing regimes in the past, and a number of recent studies that have addressed key issues in engineering education. In particular, two of these studies were funded by the Australian Learning and Teaching Council (ALTC) - King (2008) and Godfrey and King (2011); the third (King et al., 2011) was funded by ANET. These projects aimed to develop strategies to build student numbers in engineering programs and to enhance progression and graduation rates. Implementing these strategies will help to address Australia's critical skills shortages in engineering (Engineers Australia, 2008).

The three key questions to be addressed by the ALTC EngCAT project are:

1. What factors impact on the first year student experience in engineering degree programs and influence overall academic success?
2. What factors lead students to leave their undergraduate engineering program before completion, including early student departure?
3. What changes to entry requirements and pathways, (e.g., recognition of prior learning, policies and support mechanisms), could enhance retention and progression rates, and grow both student enrolment and graduate numbers?

Traditionally, engineering schools have defined a number of Year 12 subjects as pre-requisites for entry into engineering and used tertiary entrance cut-off scores to select the required quota of students. During the 1990s, some universities relaxed the number of pre-requisite subjects to counter the decline in high school students studying those subjects. At first, this increased the pool of eligible students for those universities, until their competitors followed suit. In some states, this became a chicken and egg scenario. As universities dropped a pre-requisite subject, such as Mathematics C in Queensland, fewer students selected the subject at high school. Then, due to the lack of demand, many high schools dropped Mathematics C. This further eroded the skill base of students looking to enrol in engineering and meant that engineering schools have had to provide opportunities for students to gain this prerequisite knowledge and skills.

Godfrey and King (2011) examined the reasons for the variation in the graduation rates in the participating engineering schools, including tertiary entrance cut-off scores and pre-requisite subjects. They found that while tertiary entrance scores are a reasonable predictor of success in university engineering programs, success is also achieved by students admitted using alternative criteria when appropriate support mechanisms are used (see Lowe & Johnson, 2008). Other non-cognitive factors, such as personality and learning approaches also influence student success (see Burton & Dowling, 2009). Therefore, some universities have begun using alternative measures to select, motivate, and/or retain students; three of these strategies are discussed below.

Case studies

The approaches used at three Australian universities were reviewed to help identify the factors that influence success in engineering degrees and thus the measures that should be included in a universal test. These universities developed their testing regimes in response to local retention, progression and diversity issues, and the varying contexts mean they are addressing different aspects of those issues.

The University of Southern Queensland

The University of Southern Queensland (USQ) is a regional university with a medium sized engineering school. Many of its undergraduate engineering students enter with advanced standing, based on VET or other HE qualifications, and approximately 80% study part-time by distance education. Many of USQ's students are from low socio-economic status (SES) backgrounds, particularly those from rural and remote areas. As part of the recent ALTC study (Godfrey & King, 2011), the USQ Faculty of Engineering and Surveying reviewed the progression rates of the students in a number of cohorts. It found that the graduation rate for students in the 1999 and 2003 Bachelor of Engineering and dual degree cohorts was between 55% and 60%. While many factors influence progression rates in engineering programs, it is believed that three characteristics of the USQ cohorts had a greater impact on graduation rates than they would at other universities: (a) the diversity of the educational, life and work experiences of the commencing students; (b) the distance education study mode; and (c) the impact of increased work hours resulting from skills shortages in their industry on the students who work full-time and study part-time.

Burton and Dowling began examining the learning profiles of first year USQ engineering students and their relationships with academic success in 2004. Their on-campus commencing cohort of 66 students showed that, after prior education, spatial ability and the personality trait Extraversion (i.e., assertive, social and active tendencies) were the next most important indicators of academic success in first year (as measured by GPA). They also found that students with a stronger background in mathematics, science, and technology courses at school were significantly more likely to be successful (Dowling & Burton, 2005). The test battery was adapted for online delivery in 2006 and 2007, allowing for both on-campus and distance education students to participate. The progression of commencing students in these cohorts is being tracked through to their graduation or departure from the program. However, as the majority of the students study part-time, the longitudinal studies will not be completed for another two or three years (see Burton & Dowling, 2009).

The theoretical framework that underpins this research approach recognises that individual differences in both cognitive (e.g., spatial, mathematical, and technical skills) and non-cognitive (e.g., personality traits, motivation, career interests, and approaches to learning) abilities impact on students' learning experiences and outcomes. Each student who completes the online test battery of cognitive and non-cognitive measures receives individual feedback on their learning profiles on the basis of their test results. This feedback summarises their learning approaches and major personality traits and outlines strategies for optimising their learning environments. This knowledge helps students to better understand their own motivational, attitudinal, and cognitive strengths and weaknesses, and can inform their decision to continue study engineering. The knowledge may also assist in removing stereotypical misapprehensions such as those often held by females about what is required for success in engineering.

The University of Queensland

The University of Queensland (UQ) is a Group of Eight (Go8) university with an incoming engineering cohort of over 1000. Most of its undergraduate engineering students enter directly from high school with high tertiary entrance scores. UQ students normally study full-time, on-campus and come from medium or high SES backgrounds. Over 70% of commencing students will graduate with an engineering degree. Most of the students who leave engineering do so within the first year, with approximately 30% of those leaving having passed all of the courses they attempted. Interviews with students who switched from engineering to other studies at UQ established that most had decided to do engineering very late in their school career, often based on incomplete or inaccurate information.

Since 2009, new engineering students at UQ have been completing a *Preparing for First Year Engineering* (PFFYE) competency test before starting first semester. This test consists of 60 questions focusing on fundamental knowledge (e.g., physics, chemistry and mathematics), motivations for studying engineering, learning approaches and perceived difficulties in studying. Kavanagh, O'Moore, and Samuelowicz (2009) have reported that the test results are used in three ways:

1. The cohort knowledge is reported to first year lecturers so that they can adapt their teaching accordingly (e.g., 95% of students can balance moments, and 56% can do a definite integral).
2. Each student receives a report showing which piece of knowledge is required for which first year course, thus managing the knowledge gap expectation between institution and student, and also allowing students to select courses on the basis of their previous studies (e.g., 'I need to take a physics course before I take thermodynamics').
3. The PFFYE test data is combined with demographic details of each student and their academic performance to identify students "at risk", although this has proved difficult and is an ongoing task.

Student support is provided via links to internet sites and other resources for self-study where a question was answered incorrectly.

The University of Technology Sydney

The University of Technology Sydney (UTS) is an Australian Technology Network (ATN) university with a large engineering school. Most of its undergraduate engineering students enter directly from high school with high tertiary entrance scores. They study on-campus, many part-time, and they represent all

SES backgrounds. The first year attrition rate in engineering programs is approximately 13%, although it has varied by up to 5% over the last few years. Additional data mining on student success and retention rates is currently taking place.

A 2005 review of academic performance in the undergraduate engineering programs at UTS (Lowe & Johnston, 2008) showed a relatively low correlation with Higher School Certificate results, particularly for students outside the top overall performance (OP) bands. This led to the introduction of a broader admission scheme that incorporated the results of an admission questionnaire, which aimed to provide an indication of both likely academic success and the future success as a graduate engineer. The key criteria in the questionnaire related to affinity with, and motivations for, an engineering career. In addition, it addressed both the aptitude and attitude of students in terms of emotional intelligence characteristics, similar to the non-cognitive measures included in the USQ learning profiles test battery.

The initial UTS approach was followed by a more detailed assessment, referred to as the Australian Technology Network Engineering Selection Test (ATNEST), developed by the Australian Council for Educational Research, (ACER, 2008) for the ATN. This assessment is an extended multiple choice examination that assesses students' intellectual and interpersonal capabilities to establish their aptitude to study engineering. ATNEST (ACER, 2008) enables people who do not have the required tertiary entrance score, or pre-requisite subjects, to demonstrate their prior knowledge and skills by undertaking a three-hour, on-campus test. These may be mature age students or high school students who did not meet the admission requirements. Both the UTS assessment approach and the ATNEST are intended for use by university admissions staff. Therefore, they are tools for assessing the academic and personal suitability of applicants, rather than for students to be better informed about their career options and personal fit with engineering.

Discussion

The different approaches being used by these three universities, and the alternate criteria underpinning their self-assessment measures, highlights the challenges in establishing a common national approach. However, the fact that these and other universities have recognised such tests may be useful tools for assisting students to successfully transition into their engineering programs provides an incentive to pursue such a scheme. Such an approach should identify factors related to academic success in engineering programs that are validated at the national level and across different curricula and teaching approaches. For example, we propose that the online self-assessments currently used at USQ be integrated with relevant measures from UQ (PFFYE test) and the established UTS online questionnaire (see Lowe & Johnston, 2008) to develop an online self-assessment and educational tool to enable commencing and, in future, prospective students to self-assess their readiness for, and likelihood of success in a career in engineering.

Unlike the ATNEST (ACER, 2008), however, the focus of the universal test would not be on selecting "the academically best" students or assessing prior knowledge in engineering per se. Rather it would also consider non-cognitive factors such as student's career interests, approaches to learning, and personality traits, in addition to their cognitive abilities (e.g., spatial, mathematical and technical skills) and prior knowledge and experiences. Thus, the universal test would recognise institutional differences and be built along modular lines to allow 'cherry picking' to better align with different program and cohort requirements.

Conclusion

This paper discusses the development and implementation of a cross-sector approach for testing the capabilities of first year students to facilitate entry pathways and progression rates in engineering programs. A review of approaches currently used by three Australian universities illustrates the diversity of current testing regimes, however, each approach provides some insight into key factors that impact on students' academic success and factors that influence students' decisions to persist with their engineering studies. The complexities in articulating these factors into a national approach that has the flexibility to allow for institutional differences will be challenging, yet such an approach has the potential to assist engineering schools to better identify and attract prospective students with a predisposition towards engineering, thus enhancing the likelihood of progression and retention.

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