What Do They Really Need to Know? Mathematics Requirements for Incoming Engineering Undergraduates

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Abstract

Engineering programmes in Irish universities have a minimum mathematics requirement for all incoming students. At least 55% in Higher Level Leaving Certificate mathematics (the final examination after secondary school) is required in order to enter an accredited honours engineering degree programme. However, in recent years, a wide variety of practices have developed to allow students who have not obtained the necessary mathematics grade a second chance to enter into such programmes. These practices range from one-off mathematics examinations offered by individual universities to summer schools or bridging years to allow students an opportunity to improve their mathematical skills, and the initiatives have been of mixed success.

Previous research undertaken in the Dublin Institute of Technology has shown that the greatest predictor of successful completion of first year for an engineering undergraduate is their incoming mathematics level. Therefore, with the ultimate aim of establishing the minimum level desirable for new entrants into engineering programmes, we compare the Irish situation to the approach taken in other countries with equivalent engineering qualifications. We explore some of the various "second-chance" mechanisms on offer in other countries, with a view to attracting as many students as possible into engineering programmes while maintaining necessary standards.

Introduction

Eight years ago, when the SEFI (MWG) produced the first revision to their report on a mathematics curriculum for engineers, they noted that *"in increasingly more countries, there is concern over the deterioration in the mathematical ability of new entrants to engineering degree programmes"* (SEFI, 2002, p. 3). Ireland is no exception to this experience, with studies into mathematical preparedness being undertaken as early as 1985, when Cork Regional Technical College concluded that their incoming undergraduates were deficient in basic mathematics (Cork Regional Technical College, 1985). The SEFI report goes on to state that:

> *"On its own this decline in key engineering mathematics skills amongst students who obtained reasonable entry qualifications would be a significant concern. However, it has been compounded by the trend across Europe to increase the numbers entering higher education. As a result, some students who are less qualified have started courses to which, previously, they would not have been admitted*." (SEFI, 2002, p.4)

This trend has also been noticeable in Ireland, where overall enrolment in the university sector has gone up 10.8% in the past five years (HEA, 2009, p. 14). At 42%, the percentage increase in net graduation rates across higher level education from 2001 to 2007 in Ireland was just slightly below the OECD average of 47.4% (HEA, 2009, p.71). Across the university sector as a whole, 11.8% of enrolments last year were international students (HEA, 2009), further increasing the inhomogeneity of the student cohort.

In 2002, the Retention Office in Dublin Institute of Technology (DIT) completed a study (Costello, 2002) aimed at determining whether poor numerical skills on entry were a strong predictor of failure to pass first year engineering. The results unsurprisingly showed that those with low scores in this area were highly likely to withdraw before the terminal examinations, or fail to pass the year overall. In interviews conducted with some of these students, a significant portion professed themselves to be taken aback at the strong mathematical content of an engineering programme, and felt themselves to be completely unprepared for the level of mathematics they would be studying.

All of these facts point to an increasing challenge for third-level mathematics educators in relation to the mathematics entry qualifications necessary for incoming engineering students.

Mathematics Requirements for Engineering in Ireland

In the Irish education system, the final examination taken by second-level students is called the Leaving Certificate. Students take at least six subjects, with most taking seven or eight, as their best six results are counted for entry into third-level programmes. The Leaving Certificate Mathematics examination can be taken at three different levels: Foundation, Ordinary and Higher. Within each level, fourteen possible grades can be awarded, as laid out in Table 1 below. In order to pass a subject, a student must obtain 40% or higher.

Result, *r* (%)	**Grade**	**Result, *r* (%)**	**Grade**	**Result, *r* (%)**	**Grade**
$90 \leq r \leq 100$	A1	$65 \leq r < 70$	C1	$40 \leq r < 45$	D3
$85 \leq r < 90$	A2	$60 \leq r < 65$	C2	$25 \leq r < 40$	E
$80 \leq r < 85$	B1	$55 \leq r < 60$	C3	$10 \leq r < 25$	F
$75 \leq r < 80$	B2	$50 \leq r < 55$	D1	$r < 10$	NG
$70 \leq r < 75$	B3	$45 \leq r < 50$	D2		

Table 1: Percentage range for each grade awarded at Leaving Certificate (SEC, 2009a).

Generally, to qualify for any third-level degree programme, at least a pass in Ordinary Level mathematics is required, with Foundation Level mathematics not normally accepted. However, the minimum mathematics requirement for accredited Honours Engineering degree programmes is a C3 in Higher Level Leaving Certificate Mathematics (namely, 55% or higher) or its equivalent (Engineers Ireland, 2007). Students must also obtain sufficient "points" from their other subjects and satisfy various other criteria, but the specifics of this need not concern us for the purposes of this paper. In 2009, 16.2% of Leaving Certificate students took the Higher Level Mathematics paper, with 80.8% of those who took the examination receiving a C3 or higher (SEC, 2009b). This translates to 13.1% of the overall student cohort of 2009, a total of just over 6,800 students.

Current Practices for Non-Standard Entry in Ireland

For some years, alternative entry pathways into Honours Engineering programmes have been in place in Ireland. These generally consist of two main approaches: one is to require students to first complete an Ordinary Engineering degree (which takes three years) and then, provided their grades are sufficiently high, they can enter directly into third year of an

Honours programme and complete the final two years to attain their degree (National Qualifications Authority of Ireland, 2006, pp. 22-23). The other approach involves students taking five years instead of four to complete the degree, with the first year treated as a "foundation" year and progression being dependent again on sufficiently high grades (as is the case, for example, in Dublin City University or Dublin Institute of Technology).

However, in the past couple of years, a new trend has emerged in Ireland with a number of third-level institutions offering their own supplementary mathematics examination to students who have failed to reach the mathematics requirement of a C3 or higher for Honours Engineering programmes (Qualifax, 2010). Some of these institutions impose a lower threshold that students must have achieved in their Leaving Certificate mathematics before they can take the supplementary examination; others do not. One university offers a week-long summer school to help students to prepare for the examination, while stressing that this only serves as a final preparation, with students needing to do considerable work on their own in advance (NUIG, 2010). Other institutions employ an interview process to take into account students' motivation in combination with their examination results in order to determine if they are suitable candidates for an engineering programme.

Comparing the Irish Situation with Other Countries

Initially, the intention had been to compare the pre-requisites for incoming engineering undergraduates in Ireland with those of several other European countries, and to look at their approaches to determining alternative entry procedures. However, on closer inspection, the university entry systems in many countries appear to be too different from Ireland's for this to be a useful comparison. For example, in countries such as Austria, Belgium, France and Germany, final secondary school qualifications are sufficient for entry into most university programmes, with some notable exceptions in the French Grandes Ecoles (EUA, 1999, p. 35). Ireland is, however, a signatory to the Washington Accord for engineering. As a result,

> "*qualifications accredited or recognised by other signatories are recognised by each signatory as being substantially equivalent to accredited or recognised qualifications within its own jurisdiction."* (International Engineering Alliance, 1989)

Therefore, when considering the approach taken by other countries in relation to the mathematical education of engineers, it is most appropriate to compare the Irish situation with those other Washington Accord countries with reasonably similar admission requirements. Australia and the United Kingdom are two such countries, and therefore we will now consider the situations there in some detail.

Engineering Mathematics in Australia

The Australian Mathematical Sciences Institute (AMSI) recently undertook a comprehensive, nationwide review of practices in mathematics education for engineering students (Broadbridge, 2008). Largely similar to the Irish system, Australian school students take five or six subjects in their final examinations, with almost all students opting to take mathematics, which can be studied at three different levels: elementary, intermediate and advanced (Henderson, 2009). However, enrolments are growing in elementary mathematics at the expense of the other two levels, with only 64% of high schools now offering advanced mathematics. In a situation that is mirrored all too frequently in Ireland,

> "*There is a widespread, perhaps erroneous belief that students can improve their Universities Admission Index (a national index that ranks students from their state assessments) by taking less demanding subjects."* (Henderson, 2009).

The most dramatic difference between the Irish and the Australian situations is that, as a result of this drop-off in the uptake of advanced mathematics, a large number of universities in Australia have decided to drop the requirement for incoming engineering undergraduates to have this level of mathematics. Most universities stated a decline in mathematical preparation of students entering engineering programmes and attributed this to the lowering of entry standards (Broadbridge, 2008, pp. 5-6).

Streaming in first year mathematics is commonplace, with streams usually based on the mathematics level a student has studied in school. These streams are taught separately for the first year, but are expected to have attained the same level by the end of the year, and enter a common second year. Mathematics bridging courses are offered before the start of first year by a number of universities; the delivery of these varies from classes run over the course of two weeks, to online or flexible delivery programmes, which can be completed over the course of a year.

Engineering Mathematics in the United Kingdom

The final school examination for students in the United Kingdom (excluding those in Scotland) is the A-Levels. Students generally take between three and four subjects, with an A-Level in mathematics generally required for entry into an accredited engineering degree programme. One important difference between the U.K. system and the Irish and Australian systems is that, due to the smaller number of subjects studied at A-Level, a large proportion of students do not study mathematics; in 2009, 8.6% of the A-Level cohort for that year sat the A-Level mathematics examination (Joint Council for Qualifications, 2009). Thus, choosing to lower mathematical prerequisites, such as was done in Australia, would effectively involve accepting candidates who have not studied mathematics in at least two years (and even then only to GCSE level). This is not the same choice as lowering the acceptable level of mathematics studied to the final year of schooling. However, a good discussion about the arguments for and against relaxing the A-Level mathematics requirement for engineering is given in (Kent, 2003).

A large number of universities in the U.K. offer a “foundation” year (similar to that offered by some Irish universities) to students who do not have the appropriate background for direct entry into an Honours Engineering degree programme. In addition, many innovative approaches are used once students have entered into engineering programmes, to deal with the wide variety of mathematical backgrounds present; a number of such examples can be found in (LTSN MathsTEAM, 2002), but these are beyond the scope of this discussion paper.

Conclusions and Future Work

The situation for incoming undergraduate engineering students will of necessity vary from country to country, depending on the structure of final school examinations and also the entry process for third-level programmes. Ireland has a standardised admission process for third-level education, along with a controlled national prerequisite currently in place for mathematics for accredited engineering undergraduates. However, it is clear that the student cohort entering third-level education is increasingly diverse and therefore, this may necessitate alternative entry pathways. The aim is to provide opportunities to as many suitable students as possible, while maintaining standards within the programme.

Using this paper as a starting point, we hope to conduct a collaborative, national study of how students who enter engineering programmes using these new, non-standard entry mechanisms cope in their first year of university and beyond. The idea of providing such students with a summer school in advance of any supplementary examination seems to be one which much to recommend it, and if it proves to be more successful for students who take this route than those other take other alternative routes, we will investigate the possibility of developing a standardised, short "bridging course" to ensure that students entering engineering programmes through these routes have a solid base of core mathematical skills.

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