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Improving Core Mathematical Skills in Engineering Undergraduates

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Abstract

A large number of engineering undergraduates begin their third level education with significant deficiencies in their core mathematical skills. Every year, in the Dublin Institute of Technology (DIT), a diagnostic test is given to incoming first year students, consistently revealing problems in basic mathematics. It is difficult to motivate many students to seek help in the Maths Learning Centre to address these problems. As a result, they struggle through several years of engineering, carrying a serious handicap of poor core mathematical skills, as confirmed by exploratory testing of final year students.

In order to improve these skills in engineering students, a pilot project was set up in which a 'module' in core mathematics was developed. The course material was basic, but a grade of 90% or higher was required to pass the module. Students were allowed to repeat the module as often as they liked until they passed. An automated examination for this module was developed on WebCourses, and a bank of questions created for it. Initially, this project was piloted in the third year Ordinary Degree mathematics module in Mechanical Engineering in the DIT, where it proved very successful.
Subsequently, the pilot project was extended to five Ordinary Degree engineering programmes in the DIT, across three different year-groups.

Keywords: curriculum development, e-learning, first year curriculum, mathematics modularisation

Outline of Fellowship Project

Introduction

Many students upon entry to third level engineering programmes have problems with core mathematical skills. This has been borne out in the results of diagnostic tests carried out in many third level institutions, both in Ireland (Cleary, 2007; Gill & O'Donoghue, 2007) and in the UK (LTSN MathsTEAM, 2003; Savage et al., 2000). These problems with core concepts can lead to comprehension difficulties in numerous modules, both in mathematics itself and in related subjects. In recent years, this has been exacerbated by the fact that students are being recruited from an increasingly diverse student body. The academic years of 2008 and 2009, in particular, saw the return of a large number of students to full-time education after many years in employment, due to adverse economic conditions. In this paper we discuss the maths diagnostic test carried out in the Dublin Institute of Technology (DIT) and the deficiencies in students' core mathematics revealed by this test. We then outline the details of a pilot project carried out to address these deficiencies. The results of several focus groups are presented. The maths diagnostic test was also given to a selection of fourth-year students and the results of this test are shown. Finally we outline future work we intend to carry out on this project.

Core Skills Initiative
Research conducted by the DIT Retention Office showed that a student's mathematics grade in the Irish Leaving Certificate (the final examination in the Irish secondary school system) is a key determinant in that student's progression through engineering programmes (Russell,

2005). As a result, a mathematics diagnostic test has been given to first year students for several years now and a Maths Learning Centre (MLC) has been set up in the DIT.

Mathematics Diagnostic Test

The DIT Mathematics Diagnostic Test showed marked deficiencies in core mathematical skills (Ni Fhlionn, 2006)**.** The test consists of 20 questions (ten paired questions) on basic topics such as algebra, fractions, indices, trigonometry, the equation of a line, logs, quadratic equations, simultaneous equations and basic differentiation. In 2006, the mean mark obtained by first year engineering students was 55% across all programmes. More worryingly, this mean dropped as low as 29% in some programmes. A large spread was seen within most programmes, with many students scoring significantly lower than the mean mark.

Core Skills Assessment

It was decided to set up a core skills assessment in mathematics, similar to that already in existence in the Institute of Technology Tallaght, Dublin (Marjoram et al., 2008). This consisted of a multiple-choice quiz on WebCT, based on a randomised question bank. The material covered by the test was basic but the pass mark was set at 90% for third-years and at 70% for first-years. The questions used were based on those already in use in the DIT Mathematics Diagnostic Test. Students were allowed to re-sit the assessment as frequently as required until they passed. Ideally a pass in this module would be compulsory for progression to the next year of the course, but this is not yet the case.

Pilot Project

In Ireland, students who have not achieved 55% or more in Higher Level Leaving Certificate mathematics are not eligible for the four-year Honours Degree engineering programmes, but instead may enter into a three-year Ordinary Degree programme. Upon successful completion of this, they may then enter into third year of the Honours degree. The pilot groups chosen for this study are first year Ordinary Degree students in Mechanical and Building Services, first year preliminary engineering, second year Ordinary Degree in Manutronics and third year students in the Ordinary Degree in Mechanical Engineering in DIT.

Course	Year	Leaving Certificate Points*
Preliminary Engineering	First	290
Building Services Engineering	First	150
Mechanical Engineering	First	315
Manutronics Automation	Second	150
Mechanical Engineering	Third	305

Table 7.1: List of courses included in the pilot project

*In the Irish Leaving Certificate, six subjects are included for the purpose of calculating points. A maximum of 100 points can be attained in any one subject.

Project Overview

The 'core skills assessment' was worth 10% of the mathematics module. In the first instance, the students sit the Mathematics Diagnostic. There are two different marking regimes depending on what year the students are. Third-years had to achieve a score of 90%. Those who scored 90% received nine marks out of ten, whilst those who scored less than 90% received no marks and had to take the core skills assessment at a later date. For first and

second year students a sliding scale was used, namely 70% = 4/10, 80% = 6/10 and 90–100% = 10/10. These students continued to sit the core skills assessment on a monthly basis until they achieved the required pass mark. After their first attempt, students were given access to a WebCT site with resources tailored for each question and were also encouraged to attend the MLC. After their second and subsequent attempts, special classes on problem topics were provided. At the end of the year, students were asked to fill in a reflective online survey on the core skills assessment, and selected students took part in focus groups to discuss the project.

Evaluation of the Mathematic Diagnostic Test/Core Skills Assessment

An evaluation strategy was devised in order to enhance and develop the diagnostic test and the way in which it is implemented in, and integrated into, the modules. The evaluation is essentially a comparison between aims and objectives of the development and implementing the test and the reality of the students' learning and development. However there was also a particular need for formative evaluation in order to discover areas where improvements can be made to the diagnostic test itself and its use within the engineering programmes. It was also the author's intention to obtain reliable and triangulated data that would inform the subsequent changes and refinements, and minimise the occurrence of intuitive decision-making. The evaluation combines both qualitative and quantitative research methods in order to ascertain the effectiveness of the diagnostic test and to determine where improvements can be made. The methods of data collection are questionnaires, focus groups, diagnostic test results, the number of attempts made by the students, and attendance at tutorials. It involves focus groups with different cohorts of students using the diagnostic test and hence a comparative analysis of the following groups is possible:

- Level 7 engineering first year students
- Level 7 engineering final-year students
- Level 8 engineering first year students
- Level 8 third year students
- Mature students
- Preliminary engineering students

The evaluation is to run over a complete academic year so that improvements to the test and its implementation can be made before the start of the next academic year. As this paper was written just before the end of the academic year, the evaluation process had not yet been completed in full, with only two focus groups carried out and not all quantitative data analysed, and therefore the next section presents preliminary findings.

The focus groups consisted of qualitative questions regarding the students' perceptions and opinions of the maths diagnostic test and the way in which it was implemented within their modules. They were carried out by an experienced education researcher who did not teach any of the students and was not known to the students. Analysis of the focus group data led to the following conclusions:

Positive Aspects

1. The students were able to describe the positive effects the diagnostic test had on the development of their mathematic abilities. They identified not only the ways in which their mathematical ability had developed but the role that the diagnostic test had played. They gave concise examples of difficulties they had in mathematics prior to the

test and described how these were remedied once identified through the results of the test.

2. The students were clearly aware of the formative nature and purpose of the diagnostic test even though their final mark in the test was to contribute to the overall module mark. They were also very cognisant of the need for the test to contribute to the module mark and the motivation associated with this.
3. The students supported the high pass mark and expressed their belief that it is this pass mark coupled with the fact that if they do not pass they get a mark of 0 that ensures the effectiveness of the test. It should be noted that a significant number of the preliminary engineering students felt that the pass mark of 70% was too low. This issue will be investigated further when all the data is obtained.
4. The students appreciated the chance to take the test multiple times and could clearly articulate the formative effect this had on their learning experience and development.
5. The importance in engineering of the mathematics examined by the test was evident to all students but particularly to the students in the later stages of their engineering programmes.
6. The quality of the mathematics online notes and the 'special' tutorials outside of timetabled hours was commended by the students and described as 'professional', 'effective' and 'concise'.
7. Confidence in their mathematics ability was perceived as being positively affected by the test (although it should be noted that a number of students said the result after their first attempt was disappointing and had a detrimental effect on their confidence).
8. The students appreciated the time, effort and commitment of the staff involved in the implementation of the diagnostic test.

Development Aspects

1. The diagnostic test could provide more specific feedback to the students. The students felt the effectiveness of the test could be improved if the result of the test was not just a mark but if it also suggested how the deficiencies could be rectified. For instance, the test could direct the students to a particular set of notes, chapter of a book or an online resource. In addition, if the lecturer noticed that a significant number of the students had difficulty with the same section, a tutorial could be run soon after the test to address that specific issue.
2. It was also suggested that similar diagnostic tests could be developed for specific elements of the mathematics modules. In that way, the full diagnostic test could identify areas of difficulty; the student then addresses this difficulty and can then complete a diagnostic test which only examines that particular area. The mark for this 'smaller' test would not count towards the final module mark and the student would still have the opportunity of retaking the full diagnostic test.
3. The students also expressed the view that a more advanced test could be developed for the latter stages of the engineering programmes, and for the students who excel in the diagnostic test on the first attempt.
4. All of the students expressed the opinion than the effectiveness of the test could be improved if its purpose, and the most effective way of using it, was clearly communicated to the students at the start of the process and again after the first attempt at completing the test.
5. It was suggested that greater links between the mathematics being developed within the maths modules (including the diagnostic test) and the other modules within the programmes could also improve the student mathematics ability.

Results of Diagnostic Tests

As a first step all of the students in the pilot project were given the DIT Maths diagnostic exercise. This text was also given to the first year Honours engineering class. These are the students who in the main have done higher level Mathematics for their Leaving Certificate, and provide a benchmark for the level of maths required to complete an Honours degree in Engineering. We can see that the majority of first year Honours students (69/87) have a mark of over 70% in the diagnostic exercise. Improving their core mathematics is clearly not a priority when we compare the test with the marks of other classes, and they are better than the marks of the third year students in this pilot who have already completed two years of mathematics at third level.

Overall Improvement

Throughout the lifetime of this Pilot we have seen a systematic improvement in the core mathematical skills of the students as measured by the Maths Diagnostic Test and core skills assessment. To illustrate this point we look at a case study for first year preliminary Engineering from October 2009 up to the time of writing.

Course Code and Name	Mean	Over 70%	Over 90%
DT025 first year Honours	80%	69/87	17/87
DT020 Prelim	48%	8/36	0/36
DT005/1 Building Services	65%	14/29	4/29
DT006/1 Mechanical	61%	30/72	11/72
DT003/2 Manutronics	45%	2/10	0/10
DT006/3 Mechanical	75%	16/23	7/23

Table 7.2: List of courses tested and marks received in the first test

The results below show a systematic improvement in the results of the students. On the first test only 1 out of 36 students achieved a mark of over 90%; by the time of writing this had increased to 7. More importantly 25 out of 36 failed to achieve a mark of 70% in their first attempt. This number has now been reduced to 11, with several opportunities remaining to complete the test.

Preliminary Engineering (36 students)	Mean	> 90%	> 70%	< 70%
First Attempt	54%	1	10	25
Christmas 2009	65%	6	14	16
April 2010	73%	7	18	11

Table 7.3: Grades of preliminary engineering students in the core skills assessment

Reflective Online survey

At the end of the semester all of the students in the project will be asked to complete an online survey to get their feedback on the pilot project.

Sample Group of Final Year Students

Finally, it was decided to test a small subgroup of final-year students who had already completed an Ordinary Degree and subsequently continued into the Honours Degree programme. Forty Eight students volunteered to retake the diagnostic exercise. These

students only had to take the test, no credit was awarded to them irrespective of how well or badly they did.

Final Year Engineering (48 students)	> 90%	> 70%	< 70%
Overall (48)	24	41	7
Ordinary Degree (23)	10	16	7

Table 7.4: Results of final year students

Some 24 out of 48 scored more than 90% while 41 scored more than 70%. Seven of the 48 students scored a mark of less than 70%. Of these 48 students, 23 of them came from an Ordinary Degree background, all seven students who failed to score more than 70% on the diagnostic test had come through from an Ordinary Degree, and three of these had failed to score 50%. Given that these students volunteered to do the test, there may be significantly more students in final year who still lack many core mathematical skills. These results show us that action needs to be taken early in the education of student engineers, doing ordinary degrees to address this problem.

Conclusion and Future Work

By participating in the core skills initiative there has been a systematic improvement in the core mathematical abilities of the students. This is evident both from the results of the students and the feedback we are getting from the focus groups. The results of the small group of final year Honours degree students who took the assessment have shown that there may be a significant number of students who struggle with basic mathematical concepts throughout their entire degree. Such problems are clearly endemic and will persist if not tackled in a consistent manner. The core skills assessment is one such way to encourage students to seek help to address these deficiencies, and it is extremely important that this work be rolled out across all first year courses in engineering.

Future Work

The core skills assessment will now be introduced to all first year classes doing an Ordinary Degree in Engineering. A full analysis of all the results of the tests will be carried out at the end of the academic year. The feedback from the focus groups and the online survey will be used to improve the process in the coming year. A more advanced version of the test is also being developed for students in the later years of the programme.

Recommendations to the College

1. The Core Maths Assessment should be extended to all Ordinary Degree Engineering programmes in the college.
2. A similar test should be set up for basic skills in mechanics, e.g. Resolving forces, etc.
3. We should proceed to develop a higher level version of the Core Maths Test to be administered in the third year of the Ordinary Degree. This would ensure that student are forced to revise/learn key components of the mathematics covered in college.
4. The pass mark for first year Mathematics in all first engineering year programmes should be increased to 50%.
5. There should be no choice on maths papers in the early years of all engineering programmes.

Proposed future work:

- It is envisaged that this work will be extended to other programmes in the college, both in Engineering and in the Built Environment. I am currently in consultation with lecturers both in Geomatics and Architectural Technology.
- To develop a higher level Core Maths Exercise for the third year of the Ordinary Degree.
- to continue to develop the Core Maths Assessment in the first year in response to the feedback from the focus groups including more sophisticated feedback and a series of practice tests.

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