Improving the key skills of engineering students in Mathematics

M. Marjoram[1], P. Robinson, C. O'Sullivan
Lecturers
ITT Dublin
Dublin, Ireland
E-mail: mmarjoram@ittdublin.ie probinson@ittdublin.ie cosullivan@ittdublin.ie

M. Carr
Lecturer
Dublin Institute of Technology
Dublin, Ireland
E-mail: mcarr@dit.ie

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INTRODUCTION

Since 2009 there has been a gradual trend of increasing numbers applying for Engineering and Technology based courses in Ireland [1]. Coinciding with this increase has been a fall in the preparedness of students for their course, in terms of ability in mathematics and physics. The ratio of engineering students at ITT Dublin (ITTD) with reasonably good maths (B or better in Ordinary Leaving Certificate Mathematics) to those with reasonably poor maths (C or less at OLC Mathematics) has also been roughly 30%: 70% for several years prior to 2007 [2]. These trends are well documented elsewhere – see for example Bamford [3].Several initiatives to improve basic mathematics ability have been tried at ITTD [2], [4]. These initiatives initially targeted first year students and seem to have improved retention. However, there was still a worrying lack of mathematical ability and knowledge amongst most second and third year students. The semesterised examination system does not help, leaving students with little time to reflect on their learning. To meet the challenge of helping the student bring key mathematical knowledge from one semester to the next staff at ITTD initiated a project entitled Keyskills in October 2006. The idea of the project is to continuously test key mathematical skills over a semester until a high mark is achieved (a high threshold competency based test). Such tests need to be randomized, repeatable, automatically marked, and provide immediate feedback on learning resources. The tests must be difficult to cheat and marks gained must go towards the continuous assessment for the mathematics module – a currency all students understand. Such frequent testing has been shown to be effective in motivating students to learn, especially weaker students [5].

[1] Corresponding Author: Dr M Marjoram, mmarjoram@ittdublin.ie

1 IMPLEMENTATION OF KEYSKILLS AND CORE SKILLS PROJECTS

For the last 7 years, engineering students in years 1, 2, and 3 in ITTD have been given “Keyskills” tests as part of their mathematics continuous assessment. The topics included in the tests have all been studied in earlier semesters. Most topics included are considered to be essential for the current semester’s mathematics and other modules. Sometimes a topic is included in the test because it is not covered in current semester course work but is considered to be essential in future, e.g. basic calculus. The questions are straightforward, e.g. solving a linear equation or identifying the equation of a straight line from its graph. As material tested is from earlier semesters, the first Keyskills test is in Semester 2. The tests are delivered as Moodle quizzes. Questions are drawn randomly from question banks developed by the authors covering specific topics. Each semester’s test is constructed by choosing the categories considered appropriate for that semester. From the total mathematics module 15% of the marks are assigned to Keyskills. As the intention is to encourage real competence, students receive none of this 15% until they reach a threshold of 10 correct answers. Assignment of marks against test performance is shown in *Table 1*.

Number of Correct Answers	0 – 9	10	11	12	13	14 – 15
Percent awarded out of 15%	0%	6%	7%	9%	10%	15%

Table 1. Keyskills credit versus number of correct answers

The pilot phase of implementation is detailed in Marjoram et al [4]. The roll out to all Engineering students in years 1, 2 and 3 began in September 2007 and in this paper, data for all semesters up to and including January 2013 is considered.

The ITTD Keyskills initiative has been set up as one *Moodle* [6] course that all students enrol on. This cuts down on explanatory material for students and also gives lecturing staff a single location and log on process to describe. The idea is that students will do Keyskills tests in all semesters, so that this single location is valuable for continuity of student access and login details. All student records are also kept in the same location, which allows longitudinal analysis of student performance over several semesters to be performed. Currently Keyskills consists of over 1350 questions across 50 categories with at least 20 questions in each. These are a mix of multi-choice and numerical input questions. Each question feedback has a reference to CALMAT material (available under a Creative Commons License [7]) and a well-known introductory mathematics text for Engineers. The entire Keyskills Moodle course is publicly available [8].

This Keyskills approach has been adapted for use in the Dublin Institute of Technology (DIT) under the title of Core Skills. The tests in DIT operate on a *Webcourses* [9] platform. It was introduced in 2008 to first year students covering basic mathematics [10],[11],[12]. The test consists of 20 questions covering fundamental topics for first year engineers. Those who fail to achieve a high grade receive no credit and can subsequently resit the test. The details of this vary for each course. Every lecturer who uses this system is given the freedom to implement the system as they choose. Some lecturers give no credit for a mark less than 70% whilst other lecturers require a mark of 90% before any credit is awarded. The philosophy is not to be overly prescriptive to ensure maximum buy in from staff. For the re-sit and subsequent tests there are 5 mirrors of each question which are randomly chosen, so every time the students sit the test they will receive different questions. This also makes it difficult for students to cheat as everyone is sitting a different test. Subsequently in 2011 this approach was introduced as Advanced Core Skills to students making the transition from 3rd year of an Ordinary degree into the

3rd year of an Honours degree [13]. Traditionally has been a difficult transition for students as the ordinary degree was a pathway to a qualification rather than a preparation for 3rd year of an Honours degree. Now more than 50% of students attempt to make this transition.

2 EVOLUTION OF TESTING IN RESPONSE TO STUDENT INTERACTION

During the 7 years of the Keyskills initiative, several behaviours in student learning became apparent. In particular some students' reluctance to reflect on their learning has become evident. Given the Keyskills marking structure, students are offered several (usually 6 or more) opportunities each semester to take a test. However some students exhibited no evidence of having worked on the test topics between tests. When asked about preparation for the next test, some students admitted having no record of the question categories where they gave an incorrect answer, although their performance in each individual test was readily accessible through Moodle. In September 2009 to address this problem, a "Keyskills Reflection Sheet" was introduced for third year Electronic Engineering on a pilot basis and its effectiveness was evaluated. The reflection sheet identified the question categories, both with a short description and a sample question (*Fig 1.).*

Question Type: Rearrange a formula

Q.6 Make z the subject of $r = \frac{1}{x+\sqrt{z}} + 2$	Correct ☐ Incorrect ☐	<u>Action</u>

Fig 1: Example of reflection sheet sample question

Students marked on the sheet those question categories in which they gave an incorrect answer. The sheet had to be returned to the lecturer prior to the next test with actions filled in against some or all of the incorrect answers. Recommended actions included availing of mathematics support or the use of online resources targeted at the problem category. The quality of information recorded on the reflection sheets varies. Some students are careless even about recording which questions they got wrong and give minimal or overly general "Actions", e.g. "studied" or "revised". Others fill in the forms very conscientiously and give detailed "Actions", e.g. specific online resources used.

The effectiveness of this approach was measured by comparing the performance of students in the 2009 cohort (who had used the reflection sheet) and those in prior years (who did not have the reflection sheet). As the reflection sheet is aimed at modifying student behaviour between consecutive tests, only the performance of students who took multiple tests was considered. (Note: Students who achieve 14 or 15 correct answers on their first attempt receive full marks for the Keyskills element of continuous assessment and do not resit; some students choose not to resit even though they have not received full marks). Data for Semester 5 only was included in this analysis. The number of students in third year electronic engineering who took multiple tests in semester 5 prior to the introduction of reflection sheets was 44. In 2009, there were 19 "repeating" students all of whom needed to fill in and return a reflection sheet in order to be allowed to re-sit. Those students who failed to pass the threshold of 10 right answers on their first attempt were classified as "Low Threshold" or LT students for short. The 2009 students (19 Students, 14 of whom were LT) were analysed against the 2008 class students (24 Students, 16 of whom were LT). Several hypotheses were tested to examine the effect of the introduction of reflection sheets [14]. The key result that will be reported here is analysis of the number of students reaching the threshold of 10 right answers. Comparison of students using reflection sheets in 2009 and those who had not in 2008 showed that there was a significant increase in the proportion of students who reached the threshold level of 10 correct answers. The evidence was particularly strong for students who failed to reach the threshold level on their first attempt *(Fig. 2)*. [Statistical significance was taken at the 5% level, so that any number in the analysis below 0.05 is considered to be significant.]

	All Repeating Students			**Sub-Threshold Students**		
	Passing Threshold	**Not Passing Threshold**	**p-value**	**Passing Threshold**	**Not Passing Threshold**	**p-value**
With Sheet (2009)	**18**	**1**		**13**	**1**	
No Sheet (2008)	**17**	**7**	**0.0504**	**9**	**7**	**0.0296**

Fig.2: Fisher's Exact Test: 2 × 2 Contingency Table of Passing Threshold of 10 Correct

On foot of this evidence the use of reflection sheets was extended to the other semesters. In subsequent years further innovations have been piloted with third year electronic students to incentivise the use of the reflection sheets effectively. In the last two academic years, students not providing evidence of reflection have been penalised 1% from the 15% of the module mark that is allocated to Keyskills.

Student learning behaviour regarding practice tests has also evolved. Initially in 2006 a single practice test was put in place for each semester to show students the test topics and allow practise ahead of actual tests. These practice tests had one static question in each category with no randomisation. In response to the introduction of the reflection sheets in 2009 a greater level of use of the practice tests was observed and students requested further practice tests to aid their preparation between actual test attempts. In response some new randomised practice tests were provided.

Finally, in terms of evolution of student interaction with Keyskills testing, a tendency in a small number of students to attempt to circumvent the testing system has been observed. One response to this was to examine the number of questions in the question bank and their randomisation to establish if enough randomness existed in the questions being presented to students sitting side by side while attempting a test. To do this a Visual Basic model was developed to establish the minimum number of questions needed so that students are very unlikely to be beside students doing the same question. It was discovered that the number of questions in the Keyskills question bank was more than sufficient. Also strict invigilation protocols have been put in place for Keyskills tests. Students must produce their student identification cards and the invigilator checks that they are logged in to their own account. Mobile phones must be switched off. Only one open browser screen is allowed. This can be monitored using classroom management software [15]. IP addresses are tracked to check that no Keyskills test is attempted from another location. Implementing these protocols in real time can be challenging.

3 ANALYSIS OF THE KEYSKILLS AND CORE SKILLS PROJECTS.

3.1 Test uptake for Keyskills

Module	Total Tests
Elec 2	433
Elec 3	32
Elec 5	640
Elec 6	446
Tech 2	1648
Tech 3	1254

Module	Total Students	>=5 Tests	Max. No. Tests
Elec 2	133	43	12
Elec 3	23	0	3
Elec 5	150	60	12
Elec 6	133	41	8
Tech 2	518	120	12
Tech 3	281	129	15

TechElec 4	1378
Tech 5	951
Tech 6	1099
AbMech 5	400
Total	8290

TechElec 4	286	153	18
Tech 5	266	92	12
Tech 6	285	92	14
AbMech 5	74	48	15

Table 2: Keyskills Test Frequency *Table 3: Keyskills Test Persistence*

Table 2 and *Table 3* above show the uptake of Keyskills tests in ITTD in modules from September 2007 to May 2013. From *Table 3* one can see that students are persistent, with up to 18 tests taken in some semesters. For modules with substantial numbers of students/tests it is seen that about a third of students do 5 or more tests in the semester. It is clear that the process is well understood by students and that email and text messaging of test opportunities are effective.

3.2 Semester on semester progress for Keyskills

The most complete set of student data in a single stream is for modules Tech2, Tech3, TechElec4, Tech5 and Tech6 in the Department of Mechanical Engineering. Of particular interest is whether Keyskills drives mathematical competency. Some students get 14 or 15 questions correct (yielding full marks for Keyskills) in the first 2 tests. Such students may be deemed to not really require Keyskills. This is a matter of judgement – if they sat several tests to get this mark in early semesters then perhaps Keyskills has been effective and they should count in the statistics. However, this group is omitted from the statistics which follow. Another group that is desirable to remove from our analysis is those who cheat the test in some way. To get an idea of the scale of this problem, students who scored less than 10 in their first two (or 3) tests, then scored 14 or 15 on their third (or fourth) test were considered. The incidence of such an unexpected pattern of marks was less than 0.8%. These students are excluded from the following analysis.

Table 5 below is for the 86 students who did at least 3 tests in each of semesters 2, 3, 4, 5 and 6 and did not get 14, 15 in their first two tests. *Table 5* shows that the numbers getting high marks (14, 15) in one of their tests climbs steadily. Improvements in Test 1 in semesters 3, 4, 5 and 6, and improvements in average best mark through semesters 2 to 6 are also evident, suggesting knowledge retention. Semester 2 tests mostly algebra which is covered in Semester 1. The Semester 3 test is based mostly on Semester 1 and 2 material, which students have not seen/used for some time, as the semester 3 course is statistics. This may explain the dip in the Semester 3 test statistics.

Semester	2	3	4	5	6
Average Test Score	8.88	8.62	8.40	10.29	10.35
Average Best Score	10.68	11.56	11.67	13.37	13.52
Number with 14,15	5	17	20	47	45
Average Mark in Test 1	8.11	7.19	7.86	8.01	9.13

Table 5: 86 students Semester 2, 3, 4, 5 and 6 Tech

There are results for 131 students who did tests in Semesters 3, 4, 5 and 6 and meet the other criteria for *Table 5* and are presented in *Table 6* below. There is a drop in Semester 6 for average best score which may be due to a much greater proportion of numerical input questions since 2011 (and higher number of tests) than in the previous semesters, which is borne out by looking at the semester 6 results between 2007-2010. Space does not allow us to present this data. The increase in good passing grades (14 or more) generally is encouraging.

Semester	3	4	5	6
Average Grade	8.72	8.55	10.09	10.18
Average Best Score	11.44	11.57	13.16	12.98
Number with 14,15	21	32	58	52
Average Mark in Test 1	7.45	7.72	8.01	9.00

Table 6: 131 students Semesters 3, 4, 5 and 6 Tech

3.3 Progress within a semester for Keyskills

Progress within a semester for Keyskills is generally positive. *Figure 3* shows average results within a sample of semesters for students who have done at least 5 tests. All other groups in *Table 2* show a similar trend. Students do, on the whole, get better as they take more tests though improvements are not particularly marked.

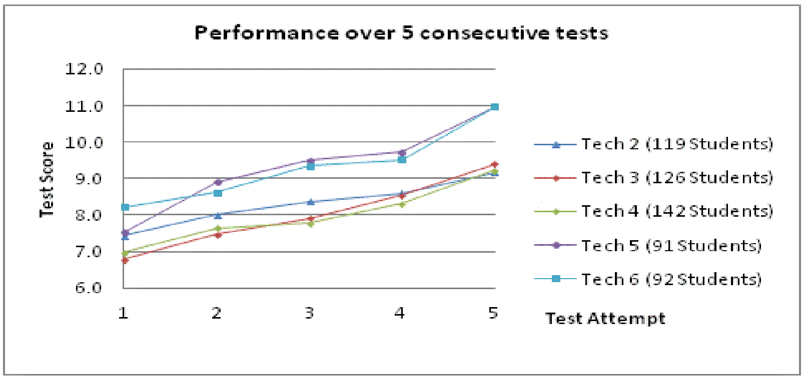

Fig. 3: Student improvement in their first 5 consecutive tests

3.4 Analysis for Core Skills

Similar analysis has also shown the Core Skills approach to be very effective with over 90% of students achieving the threshold mark before the end of term [11]. In addition focus groups were conducted with various groups of students. The students, especially mature students returning to education, were very positive about this approach as they felt it gave them a roadmap as to what was required to improve their basics. The Advanced Core Skills (also broadly similar to that used in ITTD) has also been found to be both effective and popular with students. Again this has been shown to be a very a successful approach with more than 90% of students achieving the 90% threshold mark [13]. Follow-on testing of these students is being carried out at the moment to see if the students, once they have improved their basics, actually retain the information a year later. Also examination papers are being examined to see if the students correctly use these basics under examination pressure.

4 DISCUSSION

In this section the key barriers and enablers for successfully implementing such projects to improve the key skills of engineering students in Mathematics is explored. In addition issues requiring further development are considered.

In terms of barriers to successfully implementing such projects, resource availability and 'buy-in' to the approach by other lecturing staff on the programme are the principal ones that have been identified in both institutions involved. In terms of resources, time to invigilate the multiple testing opportunities (particularly in times of economic adjustment) requires a commitment from institute management. Also computer laboratories need to be timetabled at suitable times to conduct testing. Given that the initiatives are based on implementing a common approach to student improvement across many semesters, the approval and support from other lecturing staff and programme boards which validate the overall programmes are essential. Some key enablers have also been observed. The first enabler is the existence of a collegiate approach to identifying a requirement to improve student mathematical skills and then implement an over-arching approach to achieve this. The assembling of a project team made it was possible to quickly develop a large and stable question bank and cross-programme testing approach in a way that would be impossible if one academic were attempting this alone. The second enabler was the ready availability of technical support to ensure that the computer labs hosting the testing were always reliable. Allied to this, the stable maintenance in ITTD of the e-learning platform Moodle has enabled the Keyskills project to be a reliable part of the testing environment across the programs. Finally the assignment of 15% of the mathematics module mark to Keyskills/Core Skills acknowledges students' perception of marks as a key academic currency to encourage engagement in the process.

In addition to these enablers and barriers some other issues have emerged that merit further consideration. Analysis of question topics that cause students continued difficulty has led to some interesting insights. For example, recognising equivalent forms of algebraic fractions is a topic which does not exhibit student progress across the 5 semesters and further work is required to identify how best to address this. On the broader issue of learning, several issues have been observed which are of concern as they undermine the desired goal of improving the students' approach to learning mathematics using reflection. For example, some students have shown a tendency to use the randomised practice tests as their only source of learning between the tests, rather than doing individual revision and then using the practice tests as self-tests to boost confidence ahead of taking an actual test. Also some students have tended to retake the tests many times with real progress delayed until late in the semester, rather than the preferred approach of placing emphasis on achieving the highest score possible early in the semester. Also some students have also shown an inclination to request question specific feedback rather than seeking solution or 'meta' methods for a broader problem: for example looking for feedback on a particular simultaneous equations question rather than on seeking to establish a good approach to solving any set of simultaneous equations. Currently the authors are considering ways of adjusting the way in which students interact with the Keyskills/Core Skills projects to encourage deeper and better learning approaches. For example one such measure being considered is putting a limit on the number of attempts students may make to the actual test and front-loading the opportunities for taking the tests to earlier in the semester. Consideration is also being given to limiting the number of practice tests that students may do.

The Keyskills project entered its sixth year in September 2012. Our analysis of our results so far, looking at performance on Keyskills tests over 4 and 5 consecutive semesters for different groups of students, shows evidence that students improve over a semester and that, semester on semester, students' first attempts in a new semester are better than in previous ones (hinting at long term skills retention). It is also clear that that a greater proportion of the same students gain a "high" mark as the student group proceeds through each semester. It is also worth noting that, in addition to the Keyskills/Core Skills used in mathematics, a similar approach is now being adopted in the teaching of basic science to Motor mechanic apprentices [16]. Motor mechanic apprentices attend DIT on a block release scheme for 11 weeks and then return to their job. They often only return to DIT 6 months to a year later. This means students are out of the classroom for long periods, and a testing regime like this is ideal for revising basics. In this approach the use of online testing is complemented with the construction of live electronic circuits. While this approach is still developing and has still to be fully evaluated, initial signs indicate that it is popular with students. In addition a similar approach for the teaching of mechanics to first year students is currently being developed in DIT.

In conclusion, our analysis of the data to date suggests that there is good evidence that a Keyskills/Core Skills-like testing regime, made possible by a stable quiz environment and data storage/retrieval facility, can lead to improvements in students' mathematical skills over both one semester and several semesters. There is also good evidence that forcing engagement and reflection through a reflection sheet regime can produce significant improvements in performance.

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