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How Well Do Engineering Students Retain Core Mathematical Knowledge after a Series of High Threshold Online Mathematics Tests

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Title How well do Engineering students retain core mathematical knowledge after a series of high threshold online mathematics tests ?

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Abstract
In the Dublin Institute of Technology, high threshold core skills assessments are run in mathematics for third year engineering students. Such tests require students to reach a threshold of 90% on a multiple-choice test based on a randomised question bank. The material covered by the test consists of the more important aspects of undergraduate engineering mathematics covered in the first two years of the Honours degree programme and/or the three years of the Ordinary degree programme . Students are allowed to re-sit the assessment as frequently as required until they pass. In order to measure the effectiveness of such an exercise a follow up assessment was given to students on their first day of fourth year. A comparison is made with the level of basic mathematical knowledge of these students on their first day in Third year, exactly a year previously. In addition students were surveyed on their view of, how much knowledge had been retained and how effective they felt that this approach had been.

Introduction
Dublin Institute of Technology offers students several different routes into engineering, via direct entry onto an Honours degree or alternatively entry into an ordinary degree followed by subsequent transfer to third year of the honours degree. However, these students have a wide range of mathematical abilities and prior knowledge, and many are missing the basic skills required for completion of a mathematics module at this level.
In an attempt to resolve this problem**,** an Advanced Maths Diagnostic Test (Carr et al 2013,2013b) was introduced. This test covered many of the key concepts from the early years of Engineering Mathematics. A pass-mark of 90% was set in this assessment**.** Multiple re-sit opportunities were provided, and a weighting of 10% of the continuous assessment mark for the mathematics module was given to the diagnostic test. Online resources and special classes were also introduced. This procedure has been run for the last few years and normally 80-90% of the students achieve a mark of over 90% in these basic skills.
In an attempt to assess the level of retention of these basic skills the Advanced Diagnostic tests is also given to the same students on the very first day of 4th year maths(3rd week of September). These students wouldn't have studied any mathematics since the previous January, a break of 9 months although in theory they should have been using these skills in their other engineering modules. For most students this would be the longest break they would ever have had from studying mathematics.

Methodology:
The methodology for this study involved comparing the diagnostic test scores of a group of students when they are in 3rd year and again when they are in 4th year. A questionnaire was also given to the students once they have completed the 4th year diagnostic test. 83 students took the diagnostic test in 3rd year, 66 in 4th year and 41 students completed the questionnaire. The

questionnaire was designed by the authors and was made up of seven questions with the aim of investigating student's opinions regarding the process of continuous diagnostic testing.

The diagnostic test is made up of 20 questions based on various mathematical topics. These topics include integration (6 questions), differentiation (4 questions), 1st Order Differential Equations (2questions), 2nd Order Differential Equations (2 questions), complex numbers (2 questions) and matrices (2 questions). The test is presented to students in their first mathematics lectures of 3rd and 4th year. Students are awarded 3 mark for a correct answer and -1 marks for an incorrect answer. No attempt marks are awarded.

Diagnostic Test Quantitative Results

Descriptive analysis of the results show that students performed better on the diagnostic test in their first lecture of 3rd year (Mean: 11.72, SD: 3.44) than they did in their first lecture of 4th year (Mean: 9.14, SD: 3.24). A paired samples T-test found that there was a statistically significant decrease in the mean scores of the students (t (22) = 3.812, $p < .001$) between their 3rd and 4th year.

The following table and figures show a breakdown of the student's performance in each question over both years. In comparison to their 3rd year results, 4th year students got lower scores in thirteen of the twenty questions. The main differences in scores between each year were in the in the 2nd ODE, matrices and complex number questions.

Table 1: Breakdown of diagnostic results by question and year

Question	**Question Type:**	**3rd Year % Mean**	**4th Year % Mean**	**Diff (+/-)**
1	Differentiation	100	100	No Diff
2	Differentiation	100	100	No Diff
3	2nd Order Differential Equations	27	8	-19
4	2nd Order Differential Equations	25	0	-25
5	Integration	93	94	+1
6	Integration	92	88	-4
7	Matrices	59	14	-45
8	Matrices	77	8	-69
9	1st Order Differential Equations	34	44	+10
10	1st Order Differential Equations	34	44	+10
11	Chain Rule	65	48	-17
12	Chain Rule	65	48	-17
13	Product Rule	72	48	-24
14	Product Rule	47	29	-18
15	Quotient Rule	34	61	+27
16	Quotient Rule	69	61	-8
17	Complex Numbers	51	14	-37
18	Complex Numbers	51	9	-42
19	Integration	63	48	-15
20	Integration	17	48	+31

These results are particularly interesting when they are compared with student's responses to the questionnaire on the diagnostic testing process. Although the results from both tests show a fall off in performance from year 3 to year 4, the vast majority of students (71.5%) felt it will be somewhat easier or easier to restore knowledge as a result of engagement in the continuous diagnostic testing process.

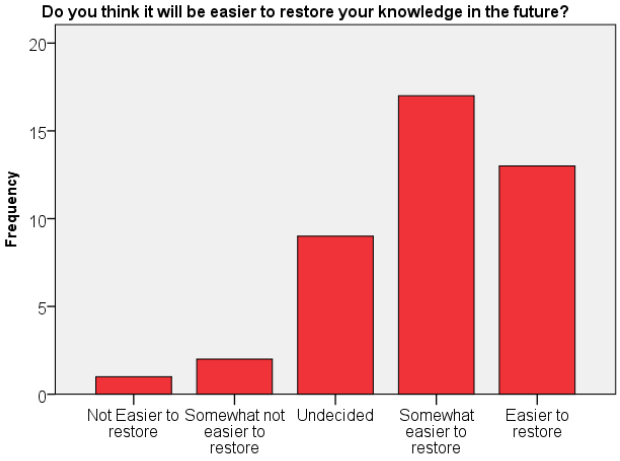

Figure 1: Students responses on whether it will be easier to restore knowledge from diagnostic testing

A closer look at each specific topic show further discrepancies between the findings. Students were asked to reflect on the diagnostic test they took in 3rd and 4th year and to indicate their level of retention in each of the topics. The two topics which students indicated the highest levels of retention were complex numbers (69.1% somewhat / very high) and matrices (66.7% somewhat / very high). However, these were the topics in which there was the biggest drop in student performance between the 3rd and 4th year tests. Between the four questions on these two topics these was an average drop of 48 percentage points from the 3rd and 4th year tests. The majority of students (47.6%) were undecided on their level of retention for the Differential Equation questions. The comparisons of test results for these questions show two different cases. Students did show good levels of retention for the 1st Order Differential Equations but poor retention for the 2nd Order Differential Equations.

Overall the results of the questionnaire indicate that students have a positive opinion of the diagnostic testing process. As Figure 2 depicts the majority of students feel that the continuous practising of skills through the diagnostic testing process has helped their performance in end of term examinations.

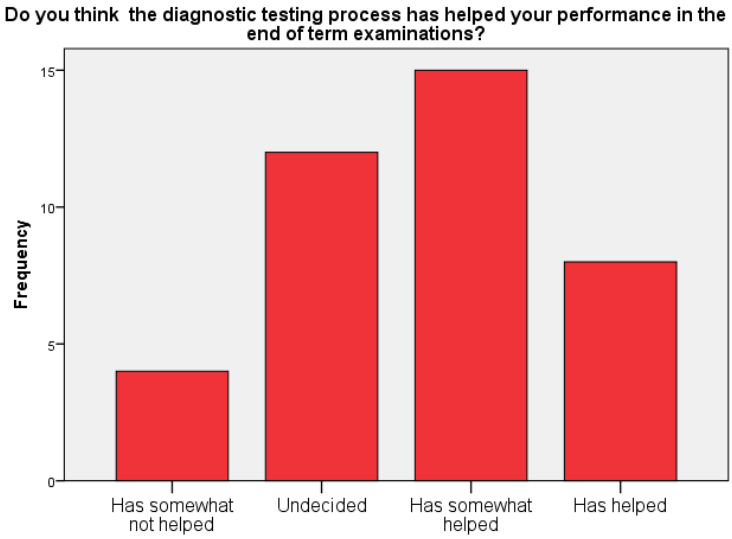

Figure2: Students responses on whether diagnostic testing has helped exam performance

Furthermore, 66.7% of students would like the diagnostic tests to be carried our more frequently. Although the pass mark for the diagnostic test is very high (90%), 47.6% of students feel that this mark is just right. Unsurprising the majority (50%) feel that it is too high.

Qualitative Synopsis of Students' Responses

1. **Reflecting on the diagnostic test you took at the start of this academic year, what was your level of retention in each topic since the last diagnostic test you took in 3rd year. Explain.**

When asked to expand on question 1 relating to students' perceptions of their retention levels of topics on the diagnostic test taken at the start of the academic year only 25% of respondents mentioned specific topics of difficulty the majority of these highlighting ODE's as being an issue. Almost 44% of students who expanded on this question referred to "poor retention levels" due to "forgetting" material or "needing revision" but did not mention specific topics. The final significant theme which emerged from students who chose to expand on this question related to a positive attitude towards the diagnostic test as 12% of students felt it encouraged them to revise/improve their skills.

2. **In areas where you had low levels of retention do you think it would be easier to restore your knowledge in the future as a result of your engagement in continuous diagnostic testing. Explain.**

Almost 60% of students who responded to this question highlighted the ability of the diagnostic test to aid memory and retention of topics which is a very positive finding one student describing it as something which helps you to "reinforce existing knowledge" (Male, Level 7). [**Fewer students (36%) focussed on the ability of the diagnostic test to aid real**

understanding of the mathematical topics contained on the test by encouraging real engagement and study of material after the test was completed].

3. **Are you addressing the areas where you feel you had low levels of retention?**

   If yes how?[i think this question may have been ambiguous some of them are talking about 3rd year and some are talking about 4th year]

Students who stated that they were addressing areas of weakness in the diagnostic test almost exclusively said they were doing so by engaging in self-study of old material and said that the diagnostic test encouraged them to study while giving them a focus and incentive for their study schedules.

If not, why not?

There were two major themes emerging from students' responses who stated that they were not addressing areas of weakness in the test –53% of respondents maintained that they there was "not enough time in the day" (Female, Level 8) to address the areas of weakness highlighted by the test. The second theme centred around pressure which students felt due to the work load they have in other areas of their degree programmes : "I have to focus on other areas of study" (Male,Level 8) "I can't as I have too much of a work load" (Male, Level 8).

4. **Do you think your continuous practising of skills through the diagnostic testing process has helping your performance in the end of term examinations? Explain.**

Two thirds of the students who responded to this question were positive towards the diagnostic test and its benefits in preparing them for end of term examinations – "It keeps you in study mode" (Male, Level 8, Mature Student) while 26% of respondents could not see the benefit of the diagnostic testing in preparing them for their end of term examination.

7. **How could the diagnostic test be improved?**

Students' opinions in relation to how the diagnostic test could be improved centred around the following 4 themes starting with the one which was most prevalent:

1. 32% of students who responded suggested that the pass mark should be lowered from 90% - "Maybe reduce the 90% pass rate slightly" (Female, Level 7).
2. 16% of students who responded had an issue with the negative marking and suggested that this be removed from the testing.
3. Another 16% requested that more tests be carried out as they found them so helpful.
4. 11% of students felt that the correct answer or some form of feedback should be provided when they got questions wrong.

The remainder of students maintained that the test was fine as it was or did not provide any suggestions for change at all.

Conclusions

We observe a significant decrease in the performance of the students from beginning of 3rd year to beginning of 4th year. Even though almost all of the students had passed an online

exam is this material their retention of the material is very poor after 9 months without any mathematics module. It is expected that this skills would have been used in an ongoing basis but it may be that there is very little actual calculation done using this mathematics material in the other modules. This needs to be explored further.
Overall the students felt positive about the process and felt the process had helped them in their third year exam and the students felt that the process did make it easier for them to retain this information in the future. It does seem that such practice of basic skills
that such practice only leads to short term memory gain. Some of the literature states that for longer term retention this material needs to be "overpracticed" over a longer period of time. "that people remember more **mathematics** and other **high school** material when learning occurs in sessions spaced out over several years" (Bahrick & Hall 1991). In addition doing the more advanced module should help with consolidation of this more basic material (Bahrick & Hall 1991) but that is not what we are seeing here. This study raises some interesting questions and requires further work included targeted focus groups with the students.

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