Implementation and Efficacy of Active Learning Strategies in Engineering Mathematics

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ABSTRACT

An engineering mathematics module has been developed and implemented to promote deeper learning using the CDIO methodology. It conforms to several CDIO Standards and also seeks to develop personal, interpersonal and professional skills through an extensive active and interactive learning paradigm. This paper discusses the content, pedagogy and efficacy of the module in relation to student motivation, engagement and attainment. It is shown that such an approach is successful in this regard.

KEYWORDS

Engineering mathematics, active and interactive learning, computer assisted assessment (CAA), computer aided learning (CAL), web-based learning, virtual learning environment (VLE), Helping Engineers Learn Mathematics (HELM).

INTRODUCTION

The School of Mechanical and Aerospace Engineering at Queen's University Belfast (QUB) has been a collaborator in CDIO (www.cdio.org) since 2003 and has an ongoing change management plan for curriculum reform based on the CDIO principle and methodology. Four years ago a new degree programme in Product Design and Development (PDD) started. This programme was developed entirely on the CDIO ethos.

The entry requirements for this new PDD degree programme were not as stringent as the School's other engineering programmes with regard to mathematical skills. In addition, there was only one engineering mathematics module scheduled in the new programme (for first year students), and this one module would therefore have to equip the students with the prerequisite mathematical skills necessary for all the other scientific and analytical modules in the whole PDD programme. The success of this single mathematics module would therefore be paramount for successfully graduating this programme.

Teaching mathematics to engineers is a worldwide issue: this is clearly seen in the extent of published work on the topic. Therefore, applying the CDIO methodology to developing such a mathematics module required careful deliberation. However, a systematic approach was applied, supported where possible by the best current pedagogical practices. It is worth noting here that in the School of Mechanical and Aerospace Engineering at QUB all engineering mathematics modules are taught by staff from the School.

In a CDIO teaching environment a key consideration was to ensure that the mathematics module could integrate with the rest of the course and espouse the same learning strategies inherent in the other more design orientated modules (CDIO Standard 7); this was considered essential if the students were to stay motivated and engaged throughout the module. Relevant learning outcomes, skills and attributes were identified by applying the CDIO methodology to course design [1] and the content was finalised by conducting interviews with all the teaching staff on the programme. The teaching methods were varied to facilitate active and interactive learning in class (CDIO Standard 8). In addition, an effective assessment strategy was implemented to promote and encourage out-of-class active learning activities. The planning, design, preparation and implementation of this module and specifically the assessment strategy employed, are described in detail in previous publications [2,3].

However, further evaluation of this module and other subsequent scientific modules provided evidence that still more needed to be done to help improve student learning with regard to mathematics. This paper describes the rationale behind developing another mathematics module for second year PDD students, based directly on the learning outcomes of the first year module, but aiming to maximize student engagement and promote deeper learning through extensive deployment of active and collaborative learning techniques. In addition, implementing the CDIO methodology with regard to module design involves "*the need to consider all possible learning opportunities for developing (student) skills and attributes, and the need to create additional learning opportunities if this is necessary*" [1], so this was the guiding axiom in the choice of pedagogy for the new module.

A variety of pedagogical techniques were investigated: the use of relevant applications, online resources, computer-aided assessment with instant feedback, and computer modeling and simulation assignments. All of these techniques could also enable the development of other non-technical CDIO Syllabus skills such as personal, interpersonal and professional skills as espoused by Armstrong and Niewoehner [1].

The pedagogy implemented in this module is discussed in detail in the following sections and the efficacy of the endeavour is presented along with data relating to the students' motivation, engagement and attainment in the course. In addition, the practical issues relating to delivering such an engineering mathematics module are discussed

RATIONALE FOR SECOND ENGINEERING MATHEMATICS MODULE

After two years of evaluating the original first-year mathematics module, it soon became evident that a significant number of students were struggling to achieve all of the intended learning outcomes. Specifically, those whose mathematical skills were weakest at entry to the PDD course were going to need more tuition.

There were several factors that helped formulate this conclusion.

- Active learning sessions.
- Homework/tutorial sheets.
- Examination.
- Second diagnostic test.

It should be noted that a diagnostic test is given to all of the students at entry to the PDD programme to determine their levels of proficiency in mathematics and target them for support.

Active Learning Sessions

The first-year mathematics module includes active learning sessions or "tasks" within the lectures [2] that allow the students to work individually or in groups to solve problems directly related to the theoretical topics presented in the lectures. These tasks only take a matter of minutes to complete, at which time the students are then invited to present their solutions. This provides excellent feedback to the lecturer and the students on their achievement of the intended learning objectives.

Homework/Tutorial sheets

As part of the assessment strategy for the first-year mathematics module a proportion of marks are allocated to coursework. Every lecture topic is accompanied by homework/tutorial sheets which contain questions relevant to that topic. The students must complete these sheets and hand them in for marking. Once marked the sheets are returned to the students and the marks logged as part of the overall assessment process. This has been shown to improve learning on the module [3]. Once again this feeds-back as instantaneous data to the students and the lecturer regarding their progress.

Exams

The aforementioned coursework is combined with an end-of-module examination to complete the assessment strategy for the first-year mathematics module. The examination includes a variety of questions covering all the key topics in the module.

Second Diagnostic Test

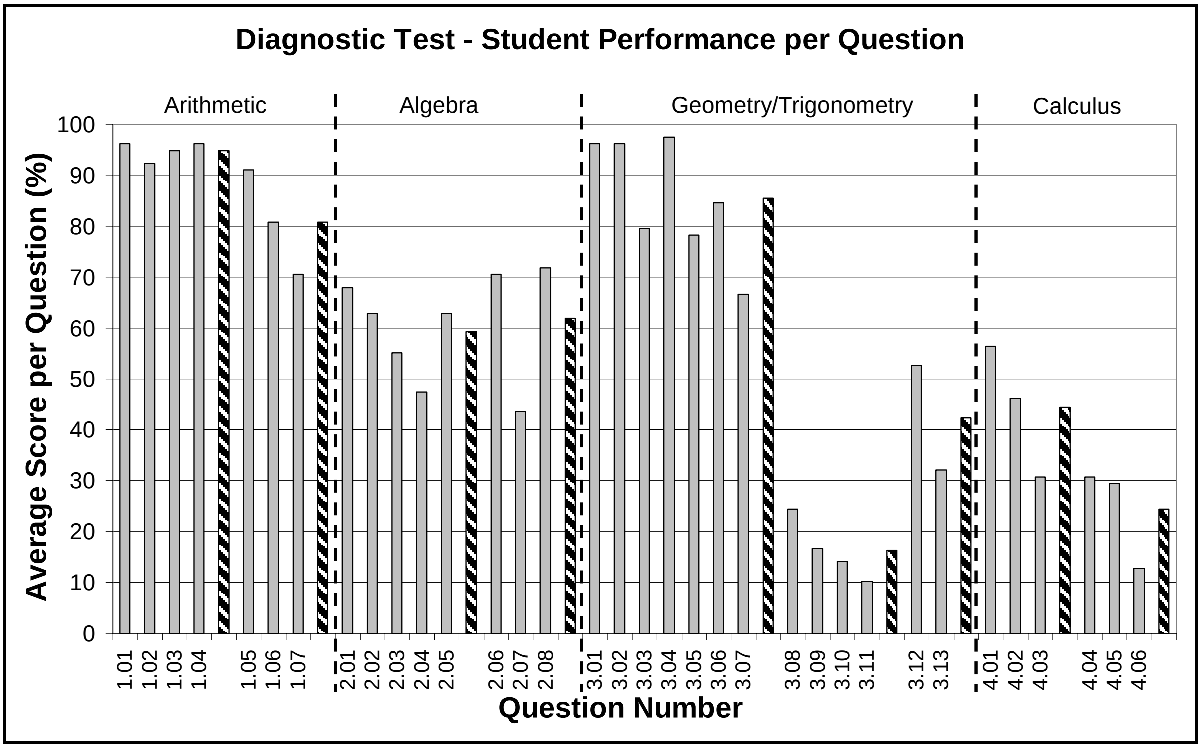

Figure 1. Graph showing results of Second Diagnostic Test

The three previous subsections explain how information was acquired that identified specific topics in the first-year mathematics module where the students did not achieve the intended learning outcomes. To corroborate this evidence, a second diagnostic test was carefully designed, based on these topics, to precisely highlight the perceived deficiencies. This test was given after the module had finished. Fig. 1 shows a graph of the results from this test: the vertical dashed lines separate the general question topics and the vertical hashed bars represent the average of the preceding group of questions.

This evidence perfectly validated what was already evident in relation to the students' perceived difficulties with the intended learning outcomes.

As part of the School's module evaluation strategy, formative feedback was also received from the students that indicated the need for more practice and support to better enhance their mathematical skills. Action had to be taken and the preferred solution was to provide another mathematics module in the second year of the PDD programme.

PLANNING AND DESIGN FOR SECOND ENGINEERING MATHEMATICS MODULE

The main objectives for this new second-year engineering mathematics module at QUB were simple:

- Provide more practice in the mathematical methods presented in the first year course.
- Promote a deeper learning environment.
- Emphasise the relevance of mathematics to the PDD degree.
- Develop other non-disciplinary skills relevant to the CDIO syllabus.

The development of the first-year mathematics module was founded on investigating the current best practice with regard to learning and teaching in the field of engineering mathematics [2,3]. Therefore, it was deemed essential that this same ethos was applied to developing the new second year module based on the clear objectives above. As such, all pedagogical decisions for the new module would be based on sound, established theory and practice.

Current Pedagogy on Teaching Mathematics to Engineers

Today, teaching engineering mathematics at tertiary level is all about providing adequate support. There are two main reasons for this:

- Students' mathematical skills at entry to university.
- Students' lack of ability to apply mathematical knowledge.

In 2003, Williamson et al. [4] described the problems with students' mathematical skills at entry to university and reported in detail on the available support resources for UK engineering and mathematics higher education communities. In 2008, Steele [5] also discussed the support issues for first year engineering mathematics students and described resources similar to those already used in the first-year mathematics module at QUB [2].

Over twenty years ago Mustoe [6] identified a serious learning issue with engineering mathematics that must be noted and resolved when implementing teaching on this subject; most students lack the ability to apply their mathematical knowledge to non-standard problems. Whereas they may be capable of performing simple exercises in manipulation, they struggle when required to use the same skills in a different or unfamiliar setting.

However, in the UK over the past ten years there has been a great deal of investment in research projects to support the teaching of engineering mathematics. Croft and Ward [7] describe in great detail the aforementioned problems facing the teachers of tertiary level engineering mathematics. They put forward a "modern and interactive" approach to ensure deeper learning in classes with broad diversities in abilities and interests, contending that normal didactic methods do not work with such a cohort. Computer Aided Learning (CAL) is one such area explored to motivate and encourage students by providing instant feedback on their progress. Therefore, Croft and Ward [7] espouse an approach that builds the best possible learning environment by exploiting the strengths of active lectures and tutorials, student centred workbooks, computer-aided learning material (linked to the workbooks) and an assessment strategy to promote continual learning outside the class. This latter point is achieved by implementing Computer Aided Assessment (CAA) which adds a force and momentum to their approach. However, Croft and Ward [7] do stipulate that such an approach requires special, well equipped workspaces.

In the same vein, Croft et al. [8] report on a specific implementation of CAA in a first year engineering mathematics module that has been thoroughly tested, evaluated and proven. They show that CAA works very well as a tool to promote learning when it is associated with coursework credit. The feedback from their students is very positive.

In a CDIO report in 2000, Lingefjärd [9] discussed issues relating to utilising computers in teaching engineering mathematics. He noted that although there had been enormous progress in computer-based technologies they were not being implemented quickly enough in a teaching environment. In such an environment he advised on the importance of aligning teaching methods with intended assessment strategies to encourage students to reflect on their own understanding of mathematics. It is now clear from the previous two references [7,8] and those contained in the rest of this section that these issues are now a priority for many authors, and indeed should be considered a priority for any new courses on the subject.

Only last year (2008), Janilionis and Valantinas [10] presented a detailed account of active learning methods being employed to teach engineering mathematics at Kaunas University of Technology in Lithuania. They adopt the same interactive approach to lectures [11] as already discussed [2,3,7], and emphasise the importance of virtual learning environments (VLEs), CAA and software applications to produce a more attractive learning experience. They successfully integrate these software applications into their engineering mathematics teaching to help the students direct their mathematical skills to unfamiliar settings and hence improve their overall learning. This incorporation of simulation exercises into the learning process provides a valuable link between the theory and real life problems, clarifying and revealing how real life processes can be transferred to mathematical models. Therefore, their students are encouraged to develop logical thinking and problem solving skills. This certainly conforms to the CDIO methodology regarding module planning by providing a learning situation where more than just specific disciplinary skills can be cultivated [1].

To date, the majority of the students enrolled on the PDD degree programme at QUB have learning styles which are predominately "technical", meaning they prefer to learn by doing [2]. To cater for different learning styles Challis and Gretton [12] advocate the use of computers and graphic calculators to provide multiple representations of mathematical concepts quickly, correctly and easily. In their opinion, developing such a rich, accessible set of mathematical tasks for the students challenges them to make decisions and interpret, explain and reflect on possible solutions. As a final point they conclude that such tasks should be enjoyable, which echoes Rossiter's standpoint [13], who also states that lecturers must "*find mechanisms for increasing student alertness and participation*" and "*find means of engaging more senses*" as a "*sense of fun helps with recall*".

Finally, in 2007 Golden and Lee [14] reported on the use of web based resources to support the teaching of engineering mathematics. They state that "r*eflective modes of study are encouraged by the interaction of computer based assessment, instant feedback and the availability of well structured response mechanisms of which web-based learning resources may form a part*". This encourages student engagement with course material. The work of Golden and Lee [14] investigates the impact of web based materials on the delivery and assessment of a first year engineering mathematics course including information on assessment results, performance in future years and student attitudes to the teaching materials. One specific point of interest here is that their students have a similar mathematical background on entry to university as the PDD students at QUB. A key conclusion is that if learning support is organized in the right way then web-based resources can encourage students to take responsibility for their own learning and achievement. Further work by these authors [15] investigates student attitudes to this web-based learning support and concludes that it is sensible and beneficial with regard to preparation time and promotes student "*reflection and engagement with their studies*".

The pedagogy discussed in this subsection provided the impetus for the way forward for the new second-year engineering mathematics module at QUB. The content of the course would focus around web-based resources, CAL, CAA and relevant simulation tasks and assignments.

MODULE CONTENT

Table 1
Handbook for the New Second-Year Engineering Mathematics Module

Module Title	**Mathematics for Product Design 2**
Module Code	MEE2035
Semester	Semester 1
Location	Ashby Building, Stranmillis Road
Prerequisite(s)	Stage 1 Mathematics for Product Design
Module Coordinator	Dr Charlie McCartan ASHBY Room 3.11 Tel: Email: c.mccartan@qub.ac.uk
Contact Hours	Mini-Lectures 6 hours Tutorials 15 hours Group Work 15 hours
Private Study	30 hours
Academic Topic	Engineering Mathematics
Rationale	Mathematics is essential to the understanding of Analytical Design and Engineering. It is used in the solving of such problems
Aims	The aim of the module is to provide further practice in the application of the mathematical knowledge required to give insight into analytical design problems and to facilitate their solution.
Learning Outcomes	Upon the successful completion of this module a student should be able to: 1. Demonstrate competence in the use of the mathematical methods listed below 2. Solve mathematical problems using these mathematical methods 3. Solve analytical design problems using these mathematical methods
Content	• BASIC ALGEBRA • EQUATION MANIPULATION • TRIGONOMETRY • BASIC CALCULUS
Learning and Teaching Methods	These include: Mini-Lectures, tutorials, group discussion, Computer Aided Learning, Computer Assisted Assessment (CAA), individual assignments. (Active and Interactive learning).
Assessment	Assessment is by 5 class tests (60%), and by 3 individual assignments (33%). The class tests are based on online HELM assessments. All class tests and all assignments must be attempted to pass this course. The combined pass mark for this module is 40%. There are marks available for attendance (7%). This is applied on a pro-rata basis for attending more than 75% of the classes.
Reading List	Required Reading: 1. Anthony Croft and Robert Davison, Mathematics for Engineers - a Modern Interactive Approach, Pearson Prentice Hall, 2nd edition, 2004. 2. Engineering Mathematics Through Applications, Kuldeep Singh 3. Engineering Mathematics, 5th edition , K.A. Stroud Other Recommended Reading: JO Bird & AJC May, 'Mathematical Formulae', Longman, 1999
Summary Description	The module provides further learning and practice in the application of Mathematical topics relevant to the Product Design and Development Course.
Virtual Learning Environment	Visit Queen's-Online for course information. In addition, access university email regularly for course info/instructions

Table 1 shows the summarized handbook information for the new second-year mathematics module. The intended learning outcomes are carefully based around the assessment strategy as this had proven beneficial in the first-year module [3]. The assessment strategy for the second-year module consists of two specific areas:

- Computer assisted assessment (CAA) using the HELM Learning Resources [2,5].
- Analytical design assignments in Microsoft Excel.

Attendance at the classes was also rewarded with a fraction of the marks from this overall assessment strategy.

All of the HELM Learning Resources and the workbooks/hand-outs from the first-year mathematics module were made available to the students on the School's VLE. In addition, a CD containing the HELM resources was given to each student so that they would always have access to this learning environment whatever their circumstances.

Computer Assisted Assessment (CAA) Using the HELM Learning Resources

There were four mathematical topics included in the learning outcomes for this second-year engineering mathematics module:

- Basic Algebra.
- Equation Manipulation.
- Trigonometry.
- Basic Calculus.

These topics related directly to the relevant sections from the first-year module and also the HELM workbooks and CAA. For each of the four topics above the students were given two to three weeks to work through the HELM CAA self-testing regime with the proviso that there would be a class-test at the end containing exact examples from the self-tests they had just completed. Each class in this two to three week period used mini-lectures, tutorial-like sessions and group discussions to support the HELM material. The class tests at the end were paper-based, lasting no more than thirty minutes. The papers were marked and returned to the students in the following class for reflective purposes and any unresolved learning issues relating to the respective mathematical topics were dealt with in that class.

Obviously, the workspace associated with this type of learning environment had to comply with these specific teaching methods being implemented. In addition, laptops were provided to the students during the classes so that they could avail of all possible resources to reinforce their potential learning.

Analytical Design Assignments in Microsoft Excel

The benefits of using simulation assignments to promote learning in engineering mathematics, while simultaneously developing other personal, interpersonal and even professional skills, have already been discussed above. The new second-year engineering mathematics module contained three such assignments. For logistical reasons, Microsoft Excel was chosen as the medium to graphically solve the real-life analytical design problems defined in the assignments; the students were already relatively familiar with Excel, but had little experience in actually applying it to a mathematical analysis scenario.

It was essential to clearly define the deliverables for these assignments and describe the problems carefully and in detail so that the students understood what was required. This ensured the students were confident in their approach to the assignment and also cultivated a sense of achievement on completing it. Continual feedback on their progress during the assignment, and at the end, was also crucial to their appreciation and even enjoyment of the task. All assignments were marked and returned to the students before the next assignment was given.

MODULE EFFICACY

Did the new module produce the desired and intended result – i.e. did it meet its objectives? Were the students, engaged, motivated and did they attain the intended learning outcomes? This section endeavours to answer these questions by providing a detailed evaluation of the new second-year engineering mathematics module in the form of both summative and formative data:

- Assessment Results
- Student Feedback

There were twelve students in this class which certainly facilitated the implementation of the new active and interactive teaching and learning methods instigated. Indeed, attempting this with a larger class would have required teaching involvement from more than one instructor.

Assessment Results

The assessment results are based on the graphs displayed in figures 2 to 5. In each of these figures the x-axis represents an individual student in the class, numbered 1 to 12 and is kept consistent throughout.

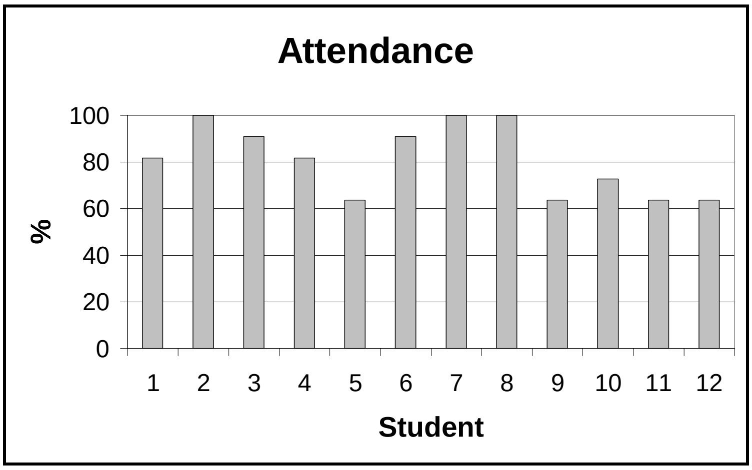

Figure 2. Graph showing the overall attendance at the new engineering mathematics module

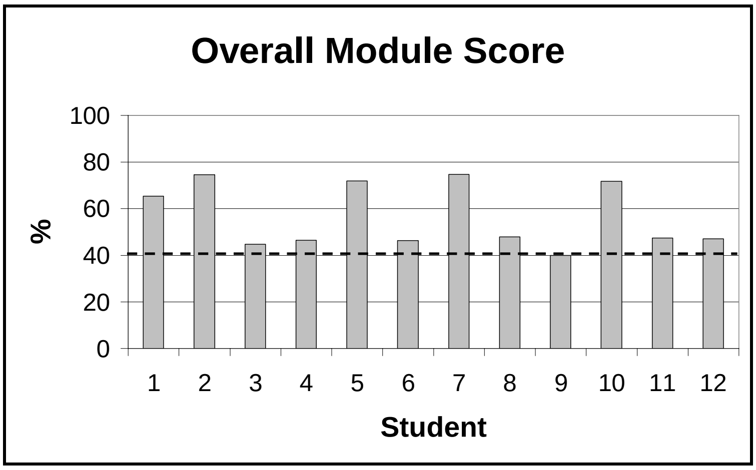

Figure 3. Graph showing the overall module assessment results

Figure 2 shows the overall attendance figures for the new second year engineering mathematics module. There were three hours of contact time per week in the twelve week semester (Table 1) and the average attendance was 81%. This would normally be regarded as excellent, but it can be seen from figure 2 that over 40% of the class (five students) did not meet the minimum requirement of 75% attendance in order to qualify for an attendance mark.

Figure 3 shows the overall performance marks for this module. Although no-one failed the module and the average score was a credible 57% (pass mark 40% - dashed line), it is evident that nearly 60% of the class (seven students) attained marks of less than 50%. Figures 4 and 5 show a breakdown of the scores attributed to the class tests and the assignments. Figure 4 shows that 33% of the class actually failed the class-tests and figure 4 confirms that everyone passed the assignments. The average scores for both these methods of assessment were 57%, but it seems that the assignments may have provided a more balanced platform of learning as there was less deviation in the marks.

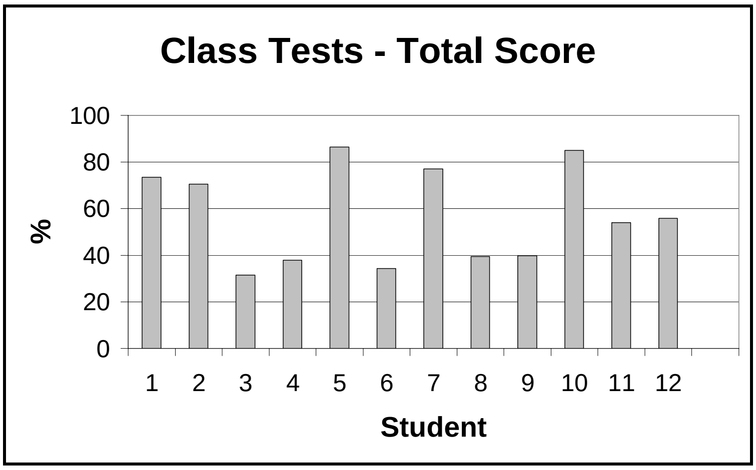

Figure 4. Graph showing the combined results of the five Class-Tests

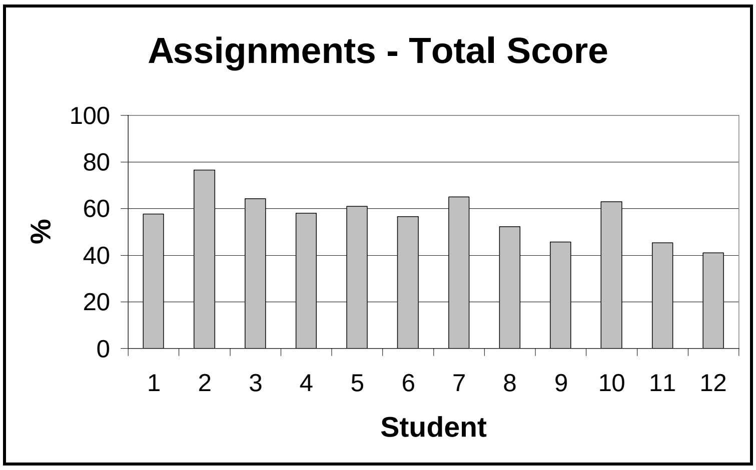

Figure 5. Graph showing the combined results of the three Excel Assignments

It can be seen from figure 3 that three out of the five students with the poorest attendance also performed in the bottom half of the class. However, one of the advantages of the teaching and learning methods employed on this module is that the lecturer/instructor really gets to know the class and soon builds a detailed understanding of an individual student's abilities and attitudes. These three students were very strategic in relation to their attendance and engagement with this class, doing just enough to pass and stay within the boundaries regulating this module as defined in the handbook in Table 1. The other two students finished with first class scores which matched their records in previous mathematical courses, so they too were strategic with their learning and confident in their mathematical ability.

This leaves four other students who had excellent attendance, but whose overall module scores were less than 50%. These particular students had also struggled on the first-year engineering mathematics module and had modest mathematical backgrounds on entry to university. Looking at their performances in the class-tests and the assignments, as shown in figs. 4 and 5, reveals an intriguing story. The students in question are students 3, 4, 6 and 8 on the x-axes of these figures and it is interesting to see that they performed poorly in the class tests but much better in the assignments in relation to the other students. There is, of course, an argument that students can collaborate on assignments and thus boost their individual scores, but a stringent policing of the assignments combined with the lecturer's own in-class observations provided adequate reassurance that this type of assessment suited these students more and appealed to their particular learning preferences in that regard. In addition, it was obvious from their engagement in-class that they certainly enjoyed the assignments more than the formal study and practice for the class tests.

Student Feedback

In line with the School's module evaluation process the students were asked to fill in a pro-forma questionnaire at the end of the new second-year engineering mathematics module. There are two sections on the questionnaire, the first asking for a score in relation to a particular statement regarding the module, to gauge overall satisfaction and identify areas of concern, and the second requiring the students to provide written comments to two open questions.

The first part of the questionnaire provided definitive proof that all of the students were satisfied with the module contents, the teaching methods, the assessment methods, the feedback and the lecturer's contributions to their learning. The results indicated a satisfaction level of over 90% for all aspects of the module.

The second part of the questionnaire indicated that the students actually appreciated and even enjoyed the active and interactive teaching and learning methods employed. The students conveyed this message by responding to two open questions:

- Please indicate the most satisfying aspect(s) of this module
- Please indicate the least satisfying aspect(s) of this module

The students' responses are shown in the following two sub-sections.

Please indicate the most satisfying aspect(s) of this module:

- "HELM Software was a very accessible and relevant tool. Continuous assessment eliminates the build-up of info for exams. Insistence on self-learning was helpful."
- "The teaching from the lecturer and he made me feel that if I had any problems I knew I could go to him for help and made me feel comfortable in doing so."
- "Found the HELM disc extremely useful for study with exams."
- "Using HELM to help throughout class."
- "Being shown where maths can be applied to real situations using Excel."
- "Well structured with clear goals."
- "Completing the tasks."
- "Good structure, feedback."
- "Different style of learning, worked well"
- "Worked well in that assignments/tests every other week gave sufficient time."
- "Very good feedback that allows you to improve on next assignment."
- "Any problems with HELM can be asked and sorted quickly."

Please indicate the least satisfying aspect(s) of this module:

- “Found the Excel assignments difficult as I did not have much previous experience with Excel”
- “Using Excel for all assignments”
- “10:00am start”
- “Not many people had much Excel experience and this made assignments more difficult.”
- “Give formal lectures on difficult topics such as differentiation and Integration.”

These comments provided further evidence on the efficacy, engagement and attainment of the students, thus indicating what was working well in the new module and what required revision.

CONCLUSIONS

It can be concluded that the active pedagogy employed in this new second-year mathematics module succeeded in motivating and engaging the students to the extent that they all passed the overall assessment process. Furthermore, the formative feedback from the students was very positive in relation to the CAL, CAA and the real life simulation assignments that the module was structured around.

Therefore employing such an active and interactive learning environment involves the students in the learning process. Clear advantages of this type of teaching and learning environment are:

- The students' understanding of basic concepts can be improved through Computer Aided Learning (CAL), Computer Assisted Assessment (CAA) and realistic simulation assignments.
- It provides students with a flexible learning medium.
- It provides the opportunity to offer constant feedback to individual students.
- It also provides instant feedback to the instructor enabling immediate and focused support for the students.
- Such two-way feedback helps develop and tailor the course.
- It provides an enjoyable and constructive learning environment which fosters a more positive attitude towards learning mathematics.

Some disadvantages to this approach are:

- The course preparation requires significantly more work for the lecturer.
- The continual assessment regime employed requires more work for the lecturer.
- In-class active and collaborative activities require a bigger commitment form the lecturer.
- The logistics of setting up CAL and CAA requires a particular IT infrastructure and significant input from the lecturer.
- Specifically adapted workspaces are required.

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