AN EVALUATION OF ACTIVE LEARNING STRATEGIES APPLIED TO ENGINEERING MATHEMATICS

Charles D McCartan
Tony McNally
J Paul Hermon

School of Mechanical & Aerospace Engineering
Queen's University Belfast

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 active and interactive learning paradigm. This paper discusses the content, pedagogy and efficacy of the module in relation to student motivation, engagement and attainment over a three year period. 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) is striving to improve its student learning experience. A curriculum change plan was already being developed when the School became a collaborator in the CDIO Initiative [1] in 2003. This is an innovative educational framework that provides students with an education stressing engineering fundamentals set in the context of Conceiving, Designing, Implementing and Operating (hence CDIO) real-world systems and products. In 2004 the School introduced a new Product Design and Development (PDD) degree programme which was designed entirely on this CDIO ethos. Extensive experience was gained in researching, developing and implementing the mathematics provision for this new PDD programme as the entry requirements were not as stringent as the School's other engineering programmes with regard to mathematical skills; an A-Level mathematics qualification was not required to enrol on the new PDD programme. In addition, there was originally only one engineering mathematics module scheduled in the new programme (for first year students), and this one module would therefore need 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.

The planning, design, preparation and implementation of this first year module, and specifically the assessment strategy employed, are described in detail by the authors in previous publications [2,3]. It was recognised that teaching mathematics to engineers is a worldwide issue, evident by the extent of published work on the topic. However, to conform to the programme ethos, the CDIO Standards (p35 of reference [1]) were carefully applied to developing this module using a systematic method, supported where possible by the best current pedagogical practices.

In such a teaching environment it was important to ensure that this mathematics module could integrate with the rest of the course and espouse the same learning strategies inherent in the other more design orientated modules (Standard 7), which was considered essential if the students were to stay motivated and engaged throughout. Relevant learning outcomes, skills and attributes were identified by applying an ordered approach to course design [4] 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 (Standard 8), which simply allowed the students to individually or collectively work on problems and then present their results [5]. In addition, an effective assessment strategy was implemented to promote and encourage out-of-class active learning [3]. It is worth noting that all engineering mathematics modules are taught “in-house” by staff from the School.

Although this first year mathematics module was very successful based on qualitative and quantitative feedback, attainment and attendance data, further evaluation of the module and other subsequent scientific modules provided evidence that more needed to be done to help further student learning with regard to mathematics. This paper describes the rationale behind developing another mathematics module for second year PDD students, based on providing more practice, analysis and relevant application of the learning outcomes of the first year module, and 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 should consider all possible learning opportunities for developing not only technical skills and attributes, but also non-technical skills such as personal, interpersonal and professional skills [4]. 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 engineering applications, online resources, computer-aided assessment with instant feedback, and computer modelling, analysis and simulation assignments. The pedagogy implemented in this module is discussed in detail in the following sections and the efficacy of the endeavour is presented over a three year evaluation period along with data relating to the students’ motivation, engagement and attainment in the course. In addition, some practical issues relating to delivering such an engineering mathematics module are discussed.

RATIONALE FOR A SECOND YEAR ENGINEERING MATHEMATICS MODULE

A diagnostic test is given to all students at entry to the PDD programme to determine their levels of proficiency in mathematics and target them for support. After two years of evaluating the first-year mathematics module, it soon became evident that those whose mathematical skills were weakest at entry to the PDD course were struggling to achieve the intended learning outcomes and were going to need more tuition, guidance and practice. There were several factors that helped formulate this conclusion: Active learning sessions; Homework/tutorial sheets; Examination; Second diagnostic test.

The first-year mathematics module includes active learning sessions or “tasks” within the lectures [2] that provide excellent feedback to the lecturer and the students on their achievement of the intended learning objectives. As part of its assessment strategy a proportion of marks are allocated to coursework and continual assessment. This has improved learning on the module [3] and feeds-back as instantaneous data to the students and the lecturer regarding their progress.

Therefore, information was continually acquired that identified specific topics in the first-year mathematics module where the students particularly struggled to achieve the intended learning outcomes. To corroborate this evidence, a second diagnostic test was carefully designed, based on these topics, to precisely highlight these perceived problem areas. This test was given to the first year PDD students after the mathematics module had finished and further 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 which would focus on developing self learning, analysis and simulation skills through the practical application of mathematics to relevant problems.

DEVELOPMENT OF SECOND ENGINEERING MATHEMATICS MODULE

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

- Provide more practice in specific mathematical methods presented in the first year course.
- Promote a deeper learning environment.
- Encourage self learning.
- Further emphasise the relevance of mathematics through analysis and simulation.
- Exploit the development of 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. 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 as discussed in the following subsection.

Current Pedagogy on Teaching Mathematics to Engineers

Today, teaching engineering mathematics at tertiary level is all about providing adequate support. The two main reasons for this are: Students' mathematical skills at entry to university [6]; and students' lack of ability to apply mathematical knowledge [7].

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. In 2001 Croft and Ward [8] described the aforementioned problems facing the teachers of tertiary level engineering mathematics and espoused a "modern and interactive" approach to ensure deeper learning. They explored Computer Aided Learning (CAL) as one such way to motivate and encourage students by providing instant feedback on their progress. They advocated a learning environment that also exploited continual learning outside the class which was achieved by implementing credited Computer Aided Assessment (CAA) [9]. However, they stipulated that such an approach requires special, well equipped workspaces. Golden and Lee [10] also promoted the use of web based resources to support the teaching of engineering mathematics by encouraging "reflective modes of study" and engagement with course material. More recently, Janilionis and Valantinas [11] further emphasised the importance of virtual learning environments (VLEs), CAA and software applications to produce more attractive learning experiences. They encouraged their students to develop non-technical skills and attributes, such as logical thinking and problem solving skills, which conforms to the CDIO methodology regarding module planning [4].

This proven pedagogy therefore provided the impetus for the way forward for the new second-year engineering mathematics module. To meet its objectives, the content of the module would focus around web-based resources, CAL, CAA and relevant simulation tasks and assignments.

MODULE CONTENT

The content of the new second-year module was based around the assessment strategy, which consists of two specific areas:

1. Computer assisted assessment (CAA) using the HELM [12] Learning Resources.
2. Analytical design assignments in Microsoft Excel.

This strategy involved continual assessment and coursework, but no final exam. The HELM Learning Resources and the resources from the first-year mathematics module were made available to the students on the School's VLE. A CD containing the HELM resources was also given to each student so that they would always have access to this learning environment.

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. Remember that the majority of the PDD students enrolled for this module would not have a Secondary qualification in mathematics (A-level) and these topics related directly to the learning outcomes from the first-year module and also the HELM workbooks and CAA. For each of the four topics above the students were given 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 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.

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, were discussed earlier, referencing key pedagogical papers. 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 and simulation 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

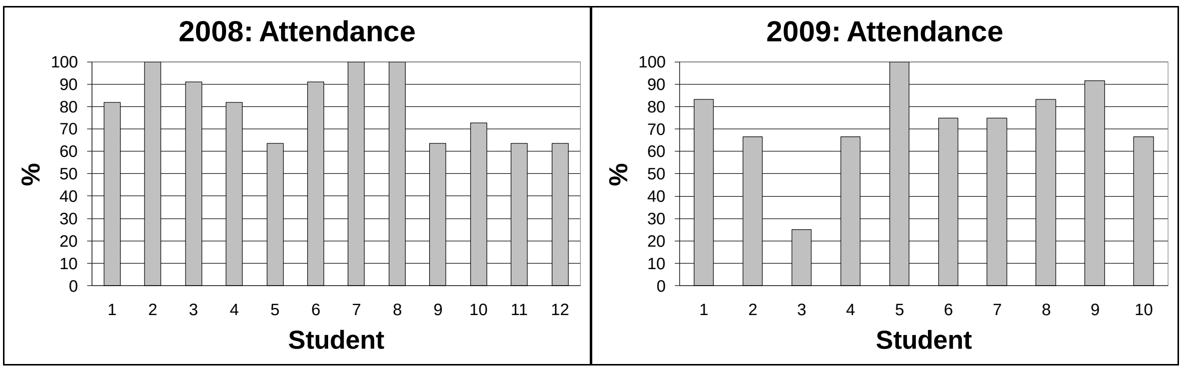
This section provides a detailed evaluation of the new second-year engineering mathematics module in the form of both summative and formative data over a three year period between 2008 and 2010 inclusive. In addition, and most importantly, in 2010 a ‘before and after’ diagnostic investigation was performed to verify that this module was indeed augmenting the students’ mathematical skills and knowledge. The module objectives are discussed in relation to student engagement, motivation and attainment.

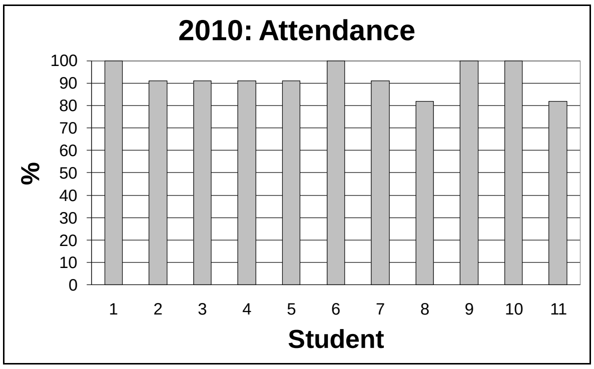
In 2008, 2009 and 2010 there were twelve, ten and eleven students respectively enrolled on the module, which certainly facilitated the implementation of the active and interactive teaching and learning methods referenced and instigated. Attempting this with a larger class would have required more teaching resources, including bigger workspaces, more postgraduate demonstrators and more computers. Obviously, the provision of timely and relevant feedback would also require more time and effort due to the inherent increased assessment workload associated with bigger classes.

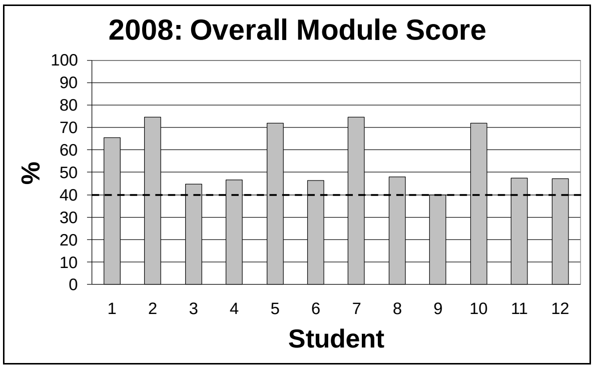
Assessment Results

The summative assessment results are illustrated in the graphs displayed in figure 1. In each of the graphs the x-axis represents an individual student in the class, numbered 1 to 12, 1 to 10 and 1 to 11 respectively for each cohort year, and is kept consistent throughout. There were three hours of contact time per week in the twelve week semester and it can be seen from the “Attendance” graphs that the average attendance was 81%, 71% and 93% respectively in 2008, 2009 and 2010.

The graphs of “Overall Module Score” show that no-one failed the module (the marks for student 5 are discounted due to external extenuating circumstances affecting their performance) and that the average score was a credible 57%, 52% and 54% respectively (pass mark 40% - dashed line). However, the graphs of “Class Tests” and “Assignments” show a respective breakdown of the overall module scores, where it can be seen that 33%, 30% and 27% of the respective cohorts failed the class-tests, but all students passed the assignments in each year. It seems that the assignments may have provided a more balanced platform of learning as there was less deviation in the marks, but it must also be considered that the students were potentially less motivated and more strategic in their approach to the class tests.




2010: Attendance
%
Student


2008: Overall Module Score
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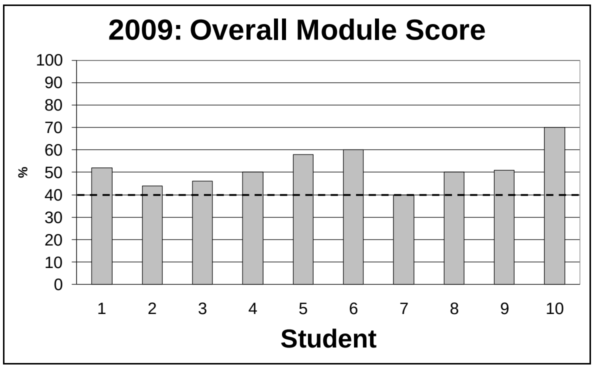
2009: Overall Module Score
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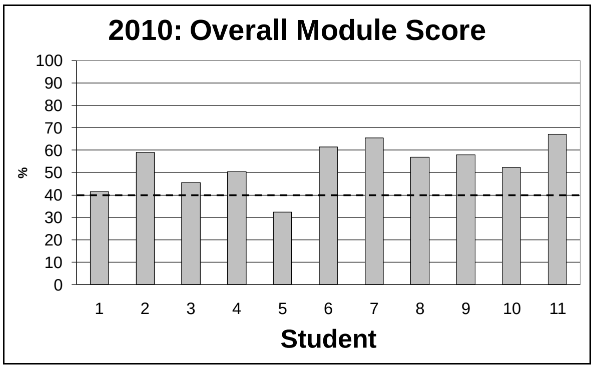
2010: Overall Module Score
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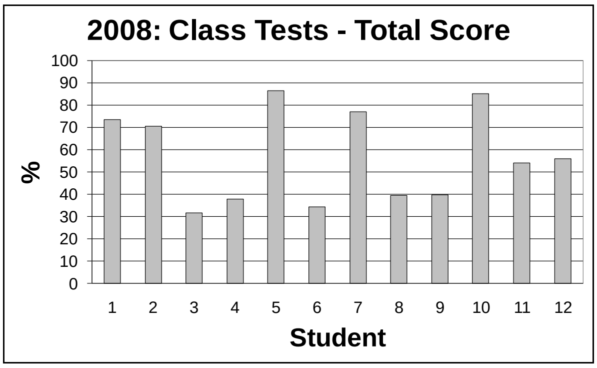
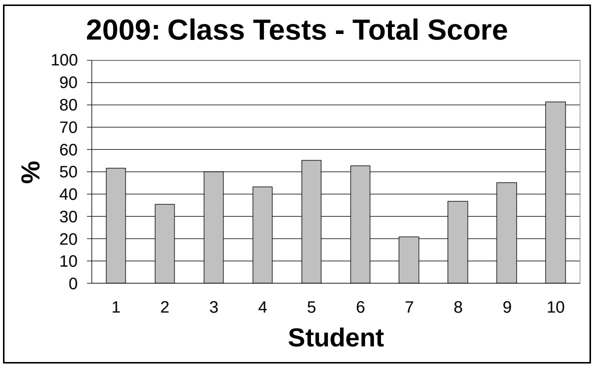

2008: Class Tests - Total Score
%
Student


2009: Class Tests - Total Score
%
Student

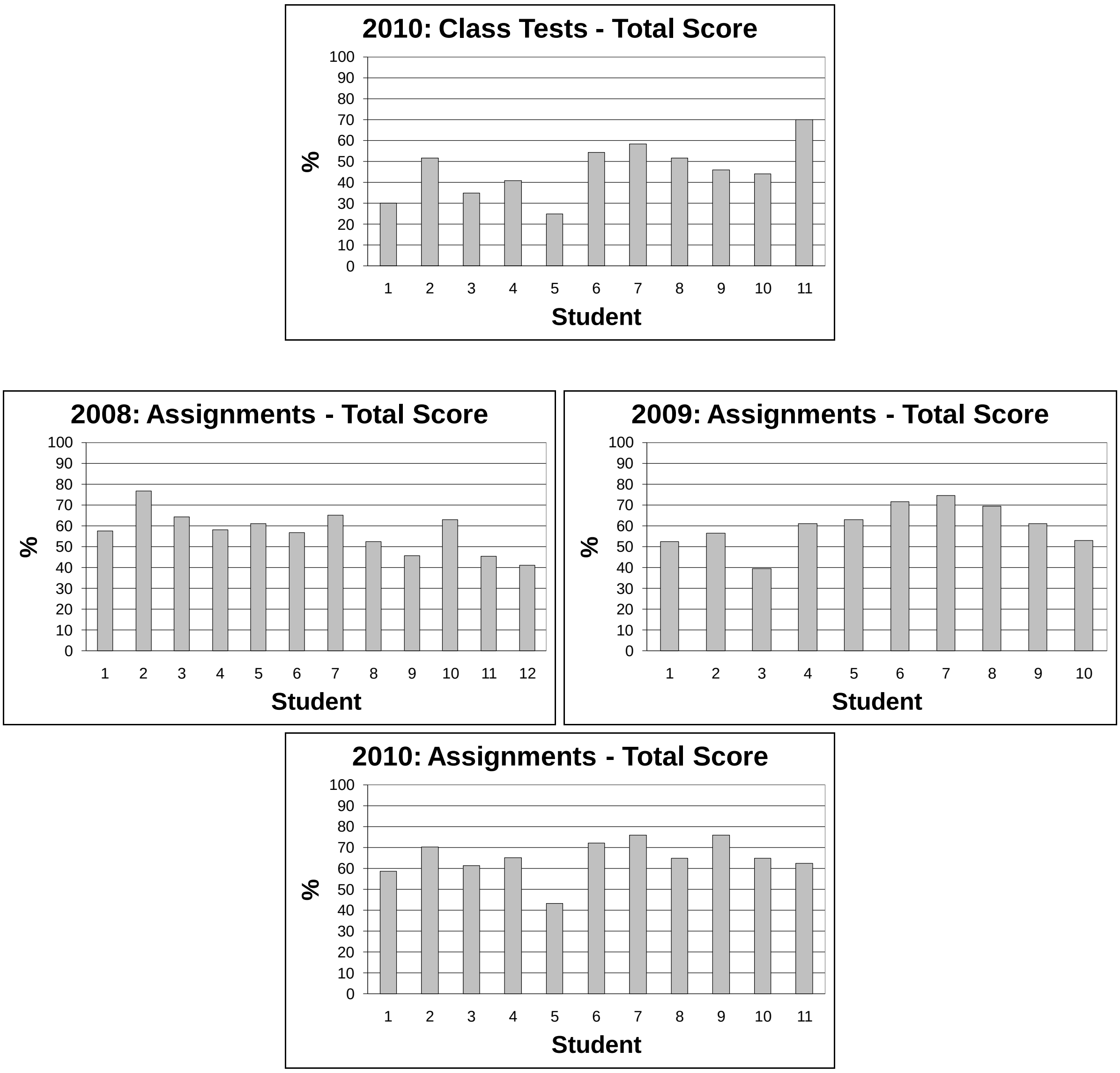


Figure 1. Summative assessment results for the new engineering mathematics module

One of the advantages of the teaching and learning methods employed on this module is that the lecturer/instructor gets to know the class very well due to all the interaction and discussions involved, and soon builds a detailed understanding of each student's individual abilities and attitudes. It was evident over the three cohorts that some students were very strategic in relation to their attendance and engagement with this module, doing just enough to pass and stay within the boundaries regulating it, and some students had excellent attendance, but their overall module scores were less than 50%. In this latter case, the students had also struggled on the first-year engineering mathematics module and had modest mathematical backgrounds on entry to university. Their performances in the class-tests and the assignments, as shown in the relevant graphs in figure 1, revealed an intriguing story - they performed poorly in the class tests but much better in the assignments in relation to the other students. However, it was evident from their engagement in-class that they appeared to enjoy the assignments more than the formal study, self learning and practice for the class tests.

At present, 60% of the assessment is attributed to the class tests and 40% to the assignments, which ensures that students cannot pass on the assignments alone. However, the disparity in average scores between the class tests and assignments (over the three year period illustrated) requires further reflection to achieve more uniformity and hence better achieve the key module objectives.

Diagnostic verification of learning

In order to provide a benchmark for learning in this second engineering mathematics module, a diagnostic test was applied at the beginning and end, based directly on the relevant mathematical topic areas. Figure 2 shows the before and after results.

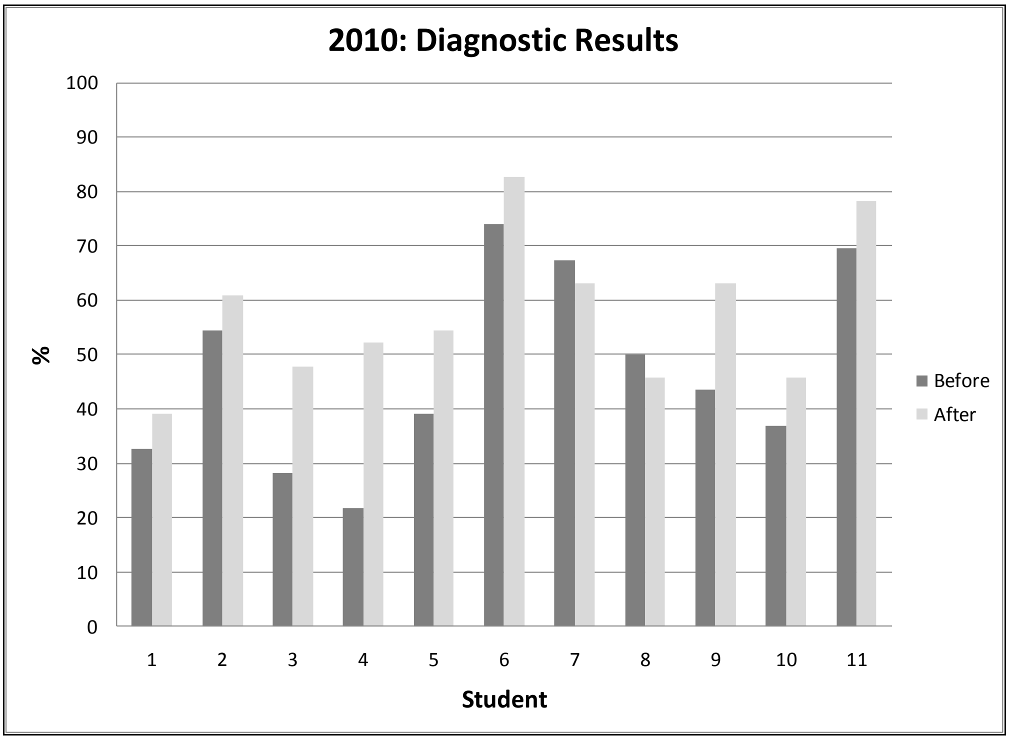


Figure 2. Results from 'before and after' diagnostic tests

Obviously, the same test was used on both occasions (without prior warning) and the results clearly show that the scores for all students bar two improved. On closer inspection with the results in figure 1, it can be seen that students 7 and 8 in 2010 had roughly similar results in the diagnostics and the class tests and so potentially 'cruised' through the CAA aspect of the module. The results are also interesting for students 3, 4 and 5 who made considerable improvements in the diagnostics, but performed poorly in the class tests.

Student Feedback

In line with the School's module evaluation process the three cohorts of students were asked to fill in a pro-forma questionnaire at the end of the new second-year engineering mathematics module. There were 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 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. Their comments also provided further evidence on the efficacy, engagement and attainment by 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 relevant simulation assignments that the module was structured around. Therefore, employing such an active and interactive learning environment engages the students in the learning process and the apparent advantages are:

- Students' understanding of basic mathematical concepts can be improved through CAL, CAA and relevant simulation assignments.
- It provides students with a flexible learning medium.
- It provides the opportunity to offer constant feedback to individual students.
- It 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 continual assessment regime employed requires more work for the lecturer.
- In-class active and collaborative activities require a bigger commitment from the lecturer.
- The logistics of setting up CAL and CAA requires a particular IT infrastructure and significant input from the lecturer.
- Workspaces are required with loose seating and computing facilities.

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Biographical Information

Charles D. McCartan is a Teaching Fellow in the School of Mechanical and Aerospace Engineering at Queen’s University Belfast. His current scholarly interests include developing applying and evaluating active and interactive learning methods, teaching mathematics to engineers, first year introductory courses and the assessment of group projects. In addition, he is a professional engineer with experience in industry, research and consultancy. He is a member of the Society of Automotive Engineers (SAE) and a Fellow of the Higher Education Academy.

Tony McNally is a faculty member in the School of Mechanical & Aerospace Engineering at Queen's University Belfast. He currently teaches Materials, Mathematics and Polymer Science. His research interests include polymer nanocomposites, biomaterials, nanomaterials and polymer blends. He is a Chartered Chemist, a Fellow of the Royal Society of Chemistry (FRSC) and a member of the Institute of Materials, Minerals and Mining.

J. Paul Hermon is a Senior Teaching Fellow in the School of Mechanical and Aerospace Engineering at Queen’s University Belfast and Program Director for the BEng and MEng Product Design and Development degrees. He is a Fellow of the Higher Education Academy and a Fellow of the Royal Society for the encouragement of Arts, Manufactures and Commerce.

Corresponding author

Dr. Charlie McCartan
School of Mechanical & Aerospace Engineering
Ashby Building, Stranmillis Road
Belfast BT9 5AH
Northern Ireland
+44 28 9097 4666
c.mccartan@qub.ac.uk