Citation: For promoting engagement and active learning in first-year mathematics through an integrated lecture-tutorial class format supported by computer-aided formative assessment.

Summary of Contribution and Specific Context

I have been a mathematics lecturer/senior lecturer at Edith Cowan University (ECU) since January 2009 and have been involved in tertiary mathematics education for 16 years. The majority of my teaching is in the large first year undergraduate mathematics units, Introductory Applied Mathematics and Calculus 1 (70 - 170 students each). Introductory Applied Mathematics delivers content at an advanced high school level, and is one of the entry pathways into Calculus 1. The combined cohort consists mainly of engineering/technology students (74.4%), with the remaining students primarily from education (13.4%), aviation (4.7%) and science (4.5%). The cohort is diverse in terms of entry pathway (only 44.1% ATAR entry), age group (only 25.3% school leavers) and nationality (25.7% international).

The significant heterogeneity of the mathematical ability of the entering cohort, and the steadily declining mathematical base upon which to build, presents a significant challenge in providing the mathematical background necessary to prepare students for more advanced studies[1,2,3]. Mathematics is a hierarchical subject, so without adequate mastery of the foundations, students are prone to pitfalls in their mathematical development[1]. It is therefore necessary to focus on approaches to best support students to improve their mathematical understanding and skill set.

It is readily accepted that mathematics is best learned by doing rather than observing, and that the majority of students only really learn when presented with a task that requires them to identify and rectify weaknesses in their understanding[4]. Successful instruction in mathematics must encourage engagement in regular active learning tasks, and provide regular feedback opportunities. A significant challenge in the context of increasing class sizes and decreasing university funding, is to provide such opportunities in a manner that is not excessively time consuming[5]. Addressing this challenge through the use of technology and instructional design has been a primary focus of my teaching efforts over the past decade.

The use of computer-aided assessment (CAA) to provide regular feedback opportunities without an onerous marking load has been a cornerstone of my approach since 2011, starting with the use of the mathematical computing package Matlab to mark assignments, and moving to the use of the commercial CAA authoring system SOWISO in 2017. CAA has a number of clear benefits compared to traditional assessments including the provision of immediate feedback, and facilitation of skills development via repeated practice[6]. Students who receive immediate feedback spend a significantly greater portion of their study time examining that feedback to identify where they went wrong, compared to students for whom feedback is delayed[7].

I have also adopted a relatively novel approach to conducting lectures in an attempt to enhance student engagement. Specifically, I have reverted to an 'old-school' active approach of developing content in real-time rather than using static pre-prepared slides, and provide opportunities for students to attempt problems at regular intervals during the lecture to avoid extended periods of passive listening. This is particularly valuable in the ECU mathematics context in which small group classes are absent, and large scale dedicated tutorials are poorly attended.

Criterion 1: Approaches to teaching and the support of learning that influence, motivate and inspire students to learn

Two key elements of my teaching approach are the utilisation of:

1. Engaging class sessions: An integrated lecture/tutorial format to break up otherwise passive lectures with opportunities to apply concepts and techniques as they are taught.
2. Regular formative feedback opportunities: CAA in conjunction with a carefully considered assessment structure to promote regular engagement and practice, provide immediate feedback, and facilitate diagnosis and rectification of misconceptions and knowledge deficiencies.

Engaging Class Sessions

Use of Tablet PC: Since 2011 I have used a tablet PC to demonstrate and record the explanation and solution of problems in front of my classes. This approach is very effective in that it allows students to follow what I am explaining as I work through the solution process; it naturally slows the pace of the presentation; it provides enhanced opportunities for students to question the solution process as it happens; and it promotes engagement, particularly when students notice that I have made a mistake. In 2015 I stopped using pre-

written slides at all during my lectures. I do not think that slides are bad in all contexts, however as a subject which involves the systematic development of ideas and definitions, and the formulation and solution of problems, mathematics lends itself to being presented in a step-by-step written form which allows me to develop these ideas in front of students in real time. This naturally slows the presentation and enhances engagement by providing an obvious focal point for students as they watch me write and draw. Everything I write in class is uploaded on Blackboard, so students can choose to watch and listen with the assurance that the class notes will be available to them later. *"I found his slightly different teaching approach this semester of not using slides and writing everything out (in calc 1) to be extremely easy to follow both watching at home and in class." (Student Evaluation, 2015). "I enjoyed the way the lectures were presented. Steven did not use slides and instead wrote everything out by hand step by step and nothing was missed. This made it very easy to follow and I feel as if the information "stuck in my head"." (Student Evaluation, 2017).*

Integrated Lecture/Tutorial: I employ an integrated lecture and tutorial format by breaking up my presentation with opportunities for the class to apply what they have just been shown. Typically I try to limit continuous lecturing to 10-15 minute blocks, in which I introduce a new idea or elaborate on a previous one, and then demonstrate one or two examples in which that idea is applied to solve a problem. I then give the students time to attempt one or more similar problems. The key advantages of this approach are:

1. It breaks up the continuous presentation of material that would previously have been delivered in a 2 hour lecture, and spreads it over two 2 hour lectures. The likelihood of students processing and retaining the material presented is improved by focussing their attention on smaller presentation intervals.
2. Students have the opportunity to gauge how well they have understood my explanation when they attempt a problem themselves, and can then focus their attention on the specific aspects that they may have struggled with when I subsequently solve the problem in front of the class. They can ask questions at the point of error or misunderstanding.
3. While the class works on problems I am able to speak to some of the students individually to identify aspects of my explanation that may not have been well understood. This is timely feedback that I would otherwise not get from students who lack the confidence to ask a question in front of the class. I can then reiterate important points when I resume presenting. *"Showing the class how to do something and explaining the theory then giving us examples to do in the lecture for each new thing we learn" (Student Evaluation – under 'best aspects', 2015). "I liked the way he would provide plenty of examples in class and have us complete questions while he was there so we could ask for assistance." (Student Evaluation, 2015).*

Regular Formative Feedback Opportunities

The inclusion of regular formative feedback opportunities throughout the semester is critical in first-year mathematics units as a means to motivate students to remain engaged, keep up with the unit content, and identify weaknesses in a timely fashion. I have used computer-based systems to provide such feedback.

Matlab Marking Code: In 2011 I wrote a code in Matlab that could mark student assignments and provide feedback via email. The assignments were set up as protected Microsoft Excel worksheets, submitted via Blackboard, marked using Matlab, and emailed back to students with feedback. The code had the flexibility to assess both numerical and symbolic expressions. In addition to assignments, students were provided with problem sets and fully worked solutions, however these were not formally assessed and therefore sometimes not submitted by students.

The Matlab marking system was effective, not only in motivating engagement, but in providing feedback in a timely fashion. Students received feedback on the day after the assignment was due, increasing the likelihood that they would process the feedback while their submission was still fresh in their minds. "*Doing assessments on all topics allowed me to get feedback on all aspects of the unit material enabling me to see where my weaknesses are." (Student Evaluation 2014). "I really like the weekly assignments as they made weekly practice essential" (Student Evaluation, 2014).*

The Matlab marking system was used in my units from 2011 until 2016, at which point I gained the financial support to trial the commercial CAA platform, SOWISO.

SOWISO: In 2017, ECU became the first university in Australasia (second in the southern hemisphere) to trial SOWISO. Although SOWISO included a number of pre-existing exercise banks, I decided to take on the significant task of authoring all of the exercises for my units to ensure consistency with the solution methods and explanations provided in class, and the phrasing of questions in tests and exams. The key benefit of

SOWISO compared to my earlier approach is that it can generate a virtually unlimited set of different exercises for students to consolidate learning; it provides immediate feedback as students work through exercises; and it gamifies learning as students see their marks and progression evolve in real time. It also provided a means to implement an assessment structure that motivates students to engage and address deficiencies in their knowledge. The key assessment components are:

1. The Essential Skills Quizzes: A set of three to five quizzes based on prerequisite concepts. The quizzes are used to provide students with clarity around the expected level of background knowledge, and to assist students to identify and rectify areas of weakness. This is of particular importance given the diversity of student backgrounds. Students have an unlimited number of attempts to achieve a minimum threshold mark for each quiz, ranging from 70% to 85%, and are provided with fully worked solutions upon completion of a quiz. All minimum thresholds must be achieved prior to the final exam in order to be eligible to pass the unit. Higher marks are awarded for timely achievement of thresholds early in the semester.
2. The Practice Exercises: A set of around 400-500 exercises which replace traditional tutorial sheets. Students are awarded marks based on the proportion of exercises answered correctly during the semester to encourage practice and consolidation. If unsure how to approach an exercise, students are able to view a fully worked solution, and then reattempt a similar exercise to test/consolidate their understanding.
3. Assignments: Each unit has six to seven topic level assignments which require students to complete exercises spanning that topic. Unlike the practice exercises, feedback and solutions are only provided once the entire assignment is submitted, however assignments can be attempted as often as necessary up to a best-before-date (highest result counts). In order to promote ongoing practice, while still encouraging timely completion of assignments, students can attempt assignments after the best-before-date, however they only receive 50% of any improvement made on an earlier attempt.

"The introduction of SOWISO was a very big help. Despite forcing repetition and more hours, it definitely helps in the end." (Student Evaluation, 2017). "Being able to have multiple attempts at our assessments really helped me in learning as it gave thorough full working for the questions I got wrong. This helped me in improving in my weaker areas." (Student Evaluation, 2017). "I feel that the use of SOWISO was a valuable aspect of the unit and also the ability to get feedback straight away on my assignments assisted me in correcting my mistakes," (Student Evaluation, 2017). "SOWISO is so much fun and so good to learn" (Student Evaluation, 2018).

Since its initial implementation I have authored SOWISO theory pages to provide further support to student learning. Each theory page contains a concise outline of the relevant theory, a number of short video recordings in which I work through an example(s), and a number of worked examples each of which can be regenerated/replaced with a different example at the click of a button. Each exercise is linked to a theory page to direct students to relevant support material if they are unable to complete the exercise. *"Mini lectures available on SOWISO were a serious help in studying and fine tuning areas of misunderstanding" (Student Evaluation, 2018). "With respect to the Theory sections on SOWISO, when I first worked through one of those I just thought "wow"! It centred me. It all made sense" (Unsolicited Student Email, 2018).*

Evidence of Impact

Exam Success: There has been a steady improvement in average exam performance over the past few years as my lecture presentations and use of CAA have been refined. The average exam results for the relevant units for 2015-2017 are shown in Figure 1.

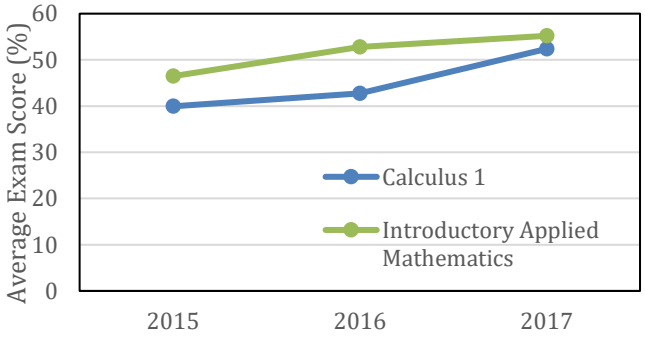

Figure 1: The average exam scores 2015-2017

Student Evaluations: Despite many students finding my units quite challenging, I consistently receive high student satisfaction scores for my lecturing and units. Student satisfaction at ECU is measured via an anonymous online survey which uses a 5 point Likert scale (-100, -50, 0, 50, 100) to produce an overall satisfaction score between -100 and 100. My average lecturer satisfaction scores for Introductory Applied Mathematics and Calculus 1 from Semester 2 2015 to Semester 1 2018 (inclusive) were 80.1 and 85.6 respectively,

compared to the ECU average of 56.8. My average unit satisfaction scores over the same period were 70.7 and 74.2 respectively, compared to the ECU average of 45.3. *"This was a great unit. Despite being challenging for me personally, plenty of help was provided through SOWISO and the lecturer." (Student Evaluation, 2018).*

SOWISO Student Perception Results: Anonymous feedback was gathered via online surveys to assess the effect of SOWISO on student engagement, motivation, confidence and perceived improvement in mathematics. The results were similar across both Introductory Applied Mathematics and Calculus 1, with 94% of students agreeing that SOWISO was a useful study tool; 70% agreeing that they felt more motivated to learn when using SOWISO, and 77% feeling more confident in their mathematics skills since using SOWISO.

Institution and External Impact

At ECU I have been a leader in the implementation of CAA within the mathematics group. In 2012, I assisted one of my more senior colleagues to set up their linear algebra assignments to be marked using the Matlab code I had developed for my units. The linear algebra assignments were administered in that form from 2012 to 2016. In 2014 I extended the Matlab code to generate and mark online tests for another colleague teaching statistics. The code generates a set of tests for the entire class, where each student is emailed a distinct version of the test, and/or a distinct data set to analyse. This ensures that students will find it more difficult to collude as they each answer different questions. The tests in this statistics unit are currently still administered using the Matlab code I developed.

"I have personally experimented with different assessment methods but have since adopted the same approach as Steve in first year, making use of code developed by him." (A/Prof Ute Mueller, 2016).

In 2017-2018, I encouraged and supported two of my colleagues to implement SOWISO in the units Foundations of Mathematics, Linear Algebra, and Differential Equations. I assisted them to set up assignments and exercises in SOWISO and modify, author and correct exercises, although they largely used existing SOWISO exercises rather than authoring their own. For Differential Equations I authored a number of exercises to cover areas of the unit for which there were no existing SOWISO exercises.

In November 2017, I presented the results of our pilot SOWISO implementation at an internal ECU teaching forum, before presenting the results again at the 2018 Teaching and Learning Forum held at Notre Dame University. The exercises I have developed in SOWISO have been shared with other universities throughout the world, including KTH Royal Institute of Technology (Sweden), The University of Groningen (Netherlands), The University of Southern Denmark, and The University of Western Australia (UWA). I actively promoted SOWISO to a colleague at UWA and provided his contact details to Marc Habbema, the cofounder of SOWISO. The UWA Department of Mathematics subsequently adopted SOWISO in 2018.

"By the way, today I received the great news that UWA is going for SOWISO for some of their units in 2018! We are really proud to expanding the community in Perth and this one is also definitely part because of you, thanks!" (Email from Marc Habbema, 15/11/17).

I believe my approach of rigorously implementing a comprehensive process of scaffolded learning has shown evidence of success both for my students and those of my colleagues with whom I share my practice.

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