TECHNOLOGY-ACTIVE STUDENT ENGAGEMENT IN AN UNDERGRADUATE MATHEMATICS COURSE

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In this paper we describe the design and implementation of a technology-active introductory first year university mathematics course. The design principles underpinning the course are presented. The results of the implementation show some areas where the technology-active approach has proven of value, as well as improvements that can be made for the next cycle. Some implications for the integration of technology in large lecture undergraduate teaching are presented.

BACKGROUND

This paper describes the implementation of a study comprising one of three components of a wider research project, led by a research team at the University of Auckland, entitled *Capturing Learning in Undergraduate Mathematics*. The *Intensive Technology Innovation* reported here investigates a digital technology initiative in an entry-level mathematics course where technology is employed in four major ways, as described in the course design principles below.

The use of technology in undergraduate mathematics is well-established with respect to lecturer use of mathematical environments (Thomas & Holton, 2003; Drijvers, 2012), and students who have used technology within components of particular courses, for example as laboratory assignments (Oates, 2011). However, it is less common for students to use technology as intensively as in this study, especially in the sense of having integrated, unrestricted use of mathematical environments and websites (such as *Matlab* & *Wolfram Alpha*) in lectures, tutorials and assessments, and being able to access these ubiquitously (in all coursework except the final exam) through smart-phones or portable computers (Hoyles & Lagrange, 2010; Oates, 2011). Such technology use in tertiary education is strongly indicated (Hoyles & Lagrange, 2010; Stewart, Thomas, & Hannah, 2005). Potential benefits include increased student engagement in mathematical activities and discourse (Scucuglia, 2006); improved inter-representational versatility (Thomas & Holton, 2003); and improved understanding in particular content areas (Thomas & Holton, 2003, Oates 2011). There are also studies that describe potential difficulties with the use of technology (e.g. see Drijvers, 2012), and Oates (2011) identifies a complex range of factors that should be considered to achieve an effective and integrated technology-active learning environment. For example, Gyöngyösi, Solovej and Winslow (2011) found evidence that weaker students commit more errors when technology is present, while Stewart, Thomas and Hannah, (2005) note that students need time for *instrumental genesis* (Artigue, 2002). Particular factors considered in the design of this study include

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teacher privileging (Kendal & Stacey, 2001); access to technology and congruence between learning and assessment (Oates, 2011); student instrumentation (Stewart, Thomas, & Hannah, 2005); technology-active, -neutral and –trivial assessment (Oates, 2011); students' use of lecture recordings (Yoon, Oates & Sneddon, 2013); and the *pragmatic, pedagogic* and *epistemic* value of technology for particular topics in the curriculum (Artigue, 2002; Stacey, 2003).

METHODOLOGY

This research follows a design experiment methodology where "a primary goal for a design experiment is to improve the initial design by testing and revising conjectures as informed by ongoing analysis of both the students' reasoning and the learning environment". (Cobb, Confrey, diSessa, Lehrer, & Schauble, 2003, p. 11). The focus of this study is a technology intervention introduced to a university mathematics course during the second semester of 2013. The research questions ask if the course design was effective in engaging students in learning mathematics, and if so how, and what improvements might be made for future cycles. What we present here are some results from the initial cycle in this continuing experimental process.

Course design principles

There are at least four guiding principles employed in the initial cycle of course design and construction. First, technology should be integral to the assessment process. Hence, each student was required to register and enrol into *MathXL* – a web-based homework, tutorial and assessment system, which was used for five skills quizzes (1% each) and the mid semester test (10%). The *MathXL* program provides instant feedback by marking student answers, identifies topics where the student needs to focus their attention and directs them to sections in an online textbook as well as creating a personalised Study Plan. The quiz and test questions were largely free-response, exercising the *MathXL* facility for numerical, algebraic and graphical input of solutions, in contrast to static multiple-choice style questions. The quizzes are a time-limited, non-supervised assessment where students have three attempts and their best score is recorded. The mid-semester test is also time-limited but held in a supervised computer lab with one attempt per question. Students were allowed access to CAS-calculators if they had them as well as online resources, although time factors would have made this impractical for most. There is still some debate about whether the test should be technology-free (skills-based) or technology-active.

The second principle was that the lecturers should model a range of appropriate technology including: a web-based graphing calculator; *YouTube* clips; applets to demonstrate critical features of mathematics; and mathematical websites. In addition to the importance of teacher-privileging (Kendall & Stacey, 2001), another reason for this was to minimise any disadvantage to students who did not have access to specific technologies. At the end of each lecture students were directed to webpages that illustrated the concepts at the heart of each topic, and a video-recording of each lecture was available to students within 24 hours. Third, students were encouraged to use any technology platform they had access to, including all calculators, mobile phones, computers, tablets, etc. and any e-resources they could access with these. The final design principle was that technology should be actively used in the one-hour weekly tutorials that all students were expected to attend.

The course consists of 36 one-hour lectures and 10 one-hour tutorials, which are worth 8% of the final grade. At the end of the course students were asked to complete three questionnaires: a technology questionnaire; an attitude survey; and the standard university student course evaluation. Three volunteers also worked on technology-active group tutorial tasks held in a computer lab. As they worked on these tasks field notes were made on an observation schedule. Each of these students had their own CAS-calculators and could use any technologies they thought appropriate. Figure 1 shows examples of the questions used in the online technology questionnaire, which contained a mix of 19 open and closed questions, and investigated student use of technology in general; mathematics-focused technology use; and the student pattern of technology use during the course. The open questions had unlimited response space.

1. Which mathematical-learning technologies did you observe the lecturers or tutors using and modeling in their teaching of MATHS 102? Please select all that are appropriate.

   MathXL ❑ Graphics or CAS calculators ❑ *Autograph* ❑ Wolfram Alpha ❑

   GeoGebra ❑ *Khan Academy* ❑ Smartphone or Tablet App ❑

   Other Internet Use (specify) ❑ ___________ Other Technology (specify) ❑ ___________

2. Which mathematics learning technologies did you personally use in the course? Please indicate your frequency of use, and whether this was the first time you had used them.

   Often = almost daily; Sometimes = 1 or 2 times per week; Seldom = a few times in the semester

   MathXL Often ❍ Sometimes ❍ Seldom ❍ Never ❍

7. What activities did you use technology for? Please specify which technologies you used for each of the following activities: [Lectures, assignments, tutorials, quizzes]

11. Describe the kind of activities you used technology for when working on mathematics problems in the course.

Figure 1: Examples of the open and closed questions from the questionnaire.

Attitude to learning mathematics with technology	Suggested goals
I like using technology to learn maths	My primary intention in using technology in maths is to check my work
Using technology in maths is worth the extra effort	My main purpose in using technology is to get the answer to the problem I'm working on
Maths is more interesting when using technology	When I use technology I aim to finish as soon as possible
Using technology hinders my ability to understand maths	My main goal in using the technology is to get a better grade in the course
I prefer working out maths by hand rather than using technology	I use the technology to find more than just the basic answer to the question

Table 1: Examples of the scale items

For the attitude survey, a Likert scale was constructed with five subscales in 29 randomised items and a range of five possible responses (strongly agree, agree, neutral, disagree, and strongly disagree). The subscales measured: attitude to maths ability; confidence with technology; attitude to instrumental genesis of technology (learning how to use it); attitude to learning mathematics with technology; and attitude to versatile use of technology. The versatility subscale had four questions and the others five. In addition, there were five questions covering possible goals in technology use, which was not a subscale. Table 1 gives examples of some items.

RESULTS

22 students (out of 131 in the course who sat the final exam) participated in the study; thirteen of these completed the questionnaire and nine the attitude survey. Responses were anonymous so it was not possible to tell how many were in the intersection of the two groups. Although this is a relatively small number of responses, we still believe it gives a reasonable indication of the student reaction to the course. In addition, 50 students completed the online course evaluation. In the questionnaire, ten of the 13 students (76.9%) agreed that the lecturers had made sufficient use of the technologies in the lectures, and recognised the use of a range of platforms. They agreed there was a wide use of technology during the course. All used *MathXL*, seven almost daily and six once or twice a week; 11 used *Desmos*, six of them daily, two once or twice a week; and six used Wolfram Alpha, five of them daily. *Khan Academy* was used daily by five students, *Autograph* by two and *GeoGebra* by one. In addition ten students made daily use of a graphic or CAS calculator.

All the students used *MathXL* for the assessment quizzes, at least once or twice a week, with a mean of 4.72 out of five quizzes. Similarly, all used it for homework, ten at least once or twice a week and twelve for revision, ten at least once or twice a week. Furthermore, nine used it in their study plan and ten for help with solving problems, mostly at least once or twice a week. For the assignments, along with various internet sites, six students mentioned using calculators, five *Desmos*, five *Khan Academy* and two each *Autograph* and *MathXL*. Nearly all the students owned a laptop (12) and a smartphone (11), with ten also having a home computer and four a tablet. Nine (69.2%) had external access to *Desmos*, five (41.7%) to *Autograph* and two (16.7%) to *GeoGebra*. On average they found *Desmos* useful (3.9 out of 5), *Autograph* slightly useful (3.33) and *GeoGebra* not useful (2.2). In response to the summary questions, twelve (92.3%) said that they thought the technology use had helped their learning of mathematics, eleven (84.6%) liked the extensive use of the technology and twelve (92.3%) wanted the technology to be available in future courses. Some comments they made included:

> I learnt a lot from this course through the many technologies made available to me. I spent several hours each week practicing using various websites, apps and online tutorials, as well as recorded lectures. Highly recommended.

> *MathXL* helped me to focus on areas of maths I needed help with.

> There was a broad use of mathematical technology throughout this course, enabling students to feel supported in the learning process…technology (for) visual learners like myself (makes) maths seems less daunting.

> Particularly in year one mathematics, the use of technology has helped me gain a quicker and deeper understanding as to how various equations behave and being able to quickly look up a mathematics problem on the internet also assisted greatly.

> [It should be used in future] Because it is really useful for understanding concepts, for practising them and learning them.

25 of the 42 open responses to the course evaluation item "What *was most helpful for your learning?*" specifically cited technology, with positive references to *MathXL* and the quizzes (17), recorded lectures (7) and access to the web (8), for example *Desmos*, *Khan Academy* and *WolframAlpha*. Comments included:

> Mainly the recorded lectures – I've found them very useful for going over when I haven't understood something or forgotten something.

> *MathXL* was extremely helpful for my learning. Being able to check my answers instantly was a great encouragement and stimulant.

> *MathXL*: The website was amazing – the instant feedback on answers and also the facilities to learn what I did wrong, as well as how to do it correctly were fantastic.

> Being prompted during lectures of other sources of information available such as *Desmos* and *Khan Academy*, to be able to be used concurrently with *MathXL*'s resources.

> I think the quizzes online are the best method for cementing your knowledge of the math.

Data from the *MathXL* website and the lecture recording access also support a high level of student engagement with the technology. While we would expect a high proportion of students to access the quizzes and the test because they are assessed (average of 95 across the 5 quizzes; 124 for the test out of 130 students), a significant number of students still engaged with revision exercises and individual study plans (e.g. 93 & 84 respectively for the test revision and 41 for an exercise on differentiation). Similarly, the lecture recordings were well used, with an average of more than 100 student-accesses to each individual lecture, and a peak of more than 200 for two lectures, one on logs and exponential functions and one on trigonometry. However, not all comments and experiences were positive. Two students in the questionnaire presented forceful reasons for a negative perspective:

> *MathXL* was a disastrously unfair method of assessment as it was difficult to formulate your thoughts when a test is in such a different format to what you have always done. I have personally always been rather good at maths but I have done very poorly in this course as I have struggled with everything being computer/technology based.

> ...too reliant on technology without understanding the core foundations of mathematics. It is like designing a bridge without first knowing fundamental engineering principles.

These sentiments were echoed in a few responses to the course evaluation item "*What improvements would you like to see?*", where comments were mostly about syntax or the use of *MathXL* in assessment, for example: “I didn't like using *Math XL* for the mid-term test.” and “I also strongly disliked *MathXL*, for multiple reasons, and I lost marks on a few questions in quizzes for incorrectly entering something rather than for getting the wrong answer.” The means of the attitude survey subscales, shown in Table 2, indicate student agreement that they have a positive attitude to their maths ability, to learning maths with technology and to versatile use of technology. The level of agreement rises in terms of their confidence in technology use and their attitude to learning how to use the technology (instrumental genesis).

Subscale	Mean* (Low-High)	Cronbach Alpha
Attitude to maths ability	3.89 (3.33-4.56)	0.695
Confidence with technology	4.42 (4.33-4.44)	0.910
Attitude to instrumental genesis	4.40 (4.11-4.56)	0.820
Attitude to learning mathematics with technology	3.93 (3.11-4.22)	0.838
Attitude to versatile use of technology	4.11 (3.67-4.44)	0.872

*Scores on negative items were reversed. 5 represents Strongly Agree.

Table 2: The means of the subscale responses and the reliability measures.

To gauge the internal consistency of the subscales the Cronbach Alpha (CA) measure of reliability was calculated. Four of the subscales show good or excellent reliability. The consistency of the subscale Attitude to maths ability is marginal (a CA of 0.7 is considered acceptable) but the CA would rise to 0.801 if the item ‘I can get good results in maths’ (mean = 3.33) were excluded. This may indicate that even those who see themselves as good at maths may be less confident of getting good results. The levels of agreement with the suggested goals for technology use were: My primary intention in using technology in maths is to check my work (4.00); My main purpose in using technology is to get the answer to the problem I’m working on (3.11); When I use technology I aim to finish as soon as possible (2.78); My main goal in using the technology is to get a better grade in the course (3.56); and I use the technology to find more than just the basic answer to the question (4.11). So while students are using technology to check their by-hand work it is often not just a basic answer. They are mostly neutral on whether they only use the technology for their current task or whether they try to finish as soon as they can, and probably do want to use the technology to get a better course grade. In Q16 of the questionnaire the students were asked ‘Describe what you see as your main goals in using technology in the course’, with space for up to three goals. Without any suggestions to lead them, nine students contributed 20 goals, most commonly: to improve learning and understanding of mathematics (6); to apply the mathematics, especially in the real world (3); and to practise mathematics (2).

Data from the group of three students working on the specially designed technology-active tasks has yet to be fully analysed. While space prohibits reproducing the tasks here, the tasks were designed with two main purposes and goals in mind:

firstly, they were non-directed problems to be worked on as a group; and secondly to facilitate and encourage active use of technology. All three volunteers were clearly enthusiastic about the use of technology; all had their own CAS-calculators, and made frequent use of the computer while working on the tasks. They were all enthused about the online graphing package *Desmos* especially its free availability and ease of use. An interesting observation came in the second tutorial, where one of the students, after they had effectively answered the set questions, used the internet to explore the nature of their findings (fitting a polynomial curve through a number of points). One negative observation was that on several occasions one or more of the students became disengaged from the group to work individually on their calculators, although the computer acted more as a focal point for the group.

The examination results at the end of the course showed a pass rate of 74.6% with 23.1% A grades, which compared well with previous corresponding semesters when technology was not integrated, such as 2012 (76.6%, 21.0%) and 2011 (77.4%, 26.4%). Thus the students were not disadvantaged by the course changes in terms of results. The student course evaluation, completed by 50 students, confirmed satisfaction with the course, with 77.1% satisfied overall with the course quality.

DISCUSSION

The evidence from this first implementation of the technology-active undergraduate mathematics course supports the value of this kind of intervention. In particular, most of the students enjoyed the experience, especially the use of *MathXL* for revision and quizzes, and were highly engaged with the mathematics through the technology. Their confidence in using the technology and attitudes to technology use of all kinds, and, importantly, to learning mathematics through the technology, were all very positive. The examination results confirm that the effect on assessed learning was at worst neutral, with clear indications that the technology had both pragmatic and epistemic value (Artigue, 2002) in facilitating understanding. There were two factors that appear to have significantly enhanced student engagement, as suggested by Scucuglia (2006). One was the relative ease of instrumental genesis of some of the technology, especially the *Desmos* program. The second was the crucial role of lecturer example, privileging the use of the technology in learning (Kendal & Stacey, 2001). This was not only noted and commented on by students but seems to have led to a wider and increased level of participation in technology use. We have learned that the attitude scale used is robust and reliable, with a minor adjustment needed to one subscale. Other lessons include the need to increase student participation (especially in the surveys and collaborative tutorials), providing information and requesting volunteers early in the course, and scheduling interviews earlier too. The positive outcomes described here, and the lessons learned from this implementation, will be taken forward into a second cycle of the course in semester one 2014. Integration of an intensive, technology-active intervention in a large undergraduate mathematics class is relatively rare. This research has demonstrated that implementing such a programme is not only feasible and can be done smoothly, free of problems, but also that it has considerable potential benefits.

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