Closing the feedback loop: Engaging students in large first year mathematics test revision sessions using pen-enabled screens

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How can active learning, peer learning and prompt feedback be achieved in large first year mathematics classes? Further, what technologies may support these aims? In this paper, we assert that test revision sessions in first year mathematics held in a technology-enhanced lecture theatre can be highly interactive with students solving problems, learning from each other and receiving immediate feedback. This is facilitated by pen-enabled screens and synchronisation software. We argue that the educational benefits achievable through the technology do outweigh the technological distractions, and that these benefits can be achieved by focused, targeted one-off sessions and not only by a semester-long, regular approach. Repeat mid-semester test revision sessions were offered on a non-compulsory basis using pen-enabled screens for all students. Students worked practice test questions and marked solutions to mathematical problems on the screens. Students’ work was then displayed anonymously for their peers to see. Answers were discussed with the whole class. We discuss outcomes from two offerings of these sessions using student feedback and lecturer reflections, and show the impact of participation on self-reported student confidence. Pedagogical approaches that the technology allowed for the first time in a large class are highlighted. Students responded uniformly positively.

Keywords: Tablet technology, undergraduate mathematics, active learning, peer learning, prompt feedback, large classes

Subject classification codes: 97U50, 97U80, 97D40

1. Introduction

‘Engaging’, ‘involved’, ‘interactive’, ‘fun’, ‘useful’, ‘cool’ – these are not usually words students would use to describe their experiences in a large first year mathematics class, particularly from a class that prepares them for a mid-semester test. In this paper we assert that a traditional, lecturer-focused session walking students through the steps of solving a practice examination, can be transformed into a highly interactive, relevant, useful and confidence-building session through the implementation of educational technologies.

We demonstrate this in the context of teaching a multivariable calculus course at an Australian university. In two consecutive years, the voluntary mid-semester test preparation sessions were held in a lecture theatre equipped with pen-enabled screens.

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These sessions aimed to facilitate active learning, encourage peer learning and create a feedback loop between students and the lecturer.

Previous research on the impact of tablet technology classes on student learning and engagement in mathematics has focused on semester-long deployment, with technology available for all or most classes. Since most universities don’t have the necessary infrastructure, such approaches may be out of reach for many. Our research shows that a positive impact can be made with a limited resource: a room equipped with fixed pen-enabled screens, where classes are held for specific purposes even just one-off. Outcomes from this research will be of interest to lecturers and to universities looking to actively engage students in mathematics courses, whilst limiting the cost of equipment. For those readers who already provide tablets to all students, our pedagogical approach to an exam preparation session will be of interest.

This paper is structured as follows. After reviewing the literature on the importance of active learning, particularly in mathematics teaching, we give an overview of technology-based strategies to engage students in large classes. We introduce the context of this study and describe the particular technology and learning environment offered in the technology-enhanced lecture theatre. Results from analysis of the feedback are summarised and discussed. We conclude with suggestions of future research directions.

2. Literature

2.1 Active learning

Chickering and Gamson [1] presented seven principles of good practice in undergraduate education: encouragement of contact between students and lecturers, development of reciprocity and cooperation among students, encouragement of active learning, delivery of prompt feedback, emphasis of time on task, communication of high expectations, and respect of diverse talents and ways of learning. In this brief overview of the literature, we will focus on one of these: Active learning. We will regard both peer learning and prompt feedback as activities that lead to active learning.

Reviewing the literature on active learning, Prince [2] defines active learning as ‘any instructional method that engages students in the learning process’, or, as cited from Bonwell and Eison [3], ‘active learning requires students to do meaningful learning activities and think about what they are doing’. It also means that a student identifies their misconceptions, and interacts with resources including the lecturer to develop their understanding. The expectation is that classroom time is used more effectively and focus is placed on developing a deeper understanding rather than the shallow repeating of material from a text book. In active learning approaches, students take responsibility for their own learning. While Prince [2] writes for engineering teaching and summarises the most relevant literature on active learning, his paper also provides a good starting point for mathematics educators.

Clark [4] questions his audience, challenging how many lecturers facilitate active learning, peer learning, and give prompt feedback. Reba and Weaver [5] show optimism in their statement that ‘today, most mathematics educators embrace active learning as a desirable classroom pedagogical style, where the instructor minimises lecture time and engages students in problem-solving via teacher-guided explorations, cooperative
group-learning experiences, or structured discussions’. This view is shared by others [6], as ‘there appears to be a shift away in conviction [from the transmission model] and some cases also practice.’

Unfortunately, anecdotal evidence, at least from Australia, contradicts this view. In reality, most first year mathematics courses are offered to non-mathematics majors such as engineering and science students. These programs tend to have large enrolments. Limited resources and cramped curricula suggest that standard first year mathematics courses are too often based on transmitting facts in lectures. Even the best lecturers struggle to develop all three principles of good practice (active learning, peer learning and prompt feedback) in a traditional lecture environment, due to physical separation between the lecturer and the students in large theatres, and resource limitations dictating that only one teaching staff member is present. This is where technology may play an important role. We will review two types of technologies; both have been shown to lead to active student learning.

2.2 Audience response systems

Audience response systems (also known as ‘clickers’) have been used to successfully foster active learning in undergraduate education [7]. They enable the lecturer to identify during class how much students think that they have understood a particular concept. In response to this feedback, class time can be used more effectively by focusing on student misconceptions, rather than emphasising concepts they already understand [8]. Kowalski, Kowalski and Gardner [8] suggest that in-class exercises to engage students should be

- well-constructed;
- thought-provoking;
- not too long to solve;

they should also

- require short answers;
- consist of the right number of questions; and
- account for individual differences among students.

However, Koile and Singer [9] make a good argument that clickers assess recognition, not recall when students select from given answers. This does not imply that the student can actually solve a problem from beginning to end. A further limitation in mathematics teaching is that students may take short cuts to find the correct answer by using an informed guess. They may also reverse-engineer the question (an excellent example is: students are instructed to find an antiderivative, but instead identify the correct answer by calculating derivatives of the given choices of antiderivatives).

2.3 Tablet PCs to facilitate active learning

The single-tablet PC model, where the lecturer annotates electronically and may incorporate student input, has been shown to lead to a more dynamic and engaging lecture environment with increased student interaction. Lecturers have observed that they are more motivated when using this technology, and this enthusiasm transfers to the students [10]. Experiences across a number of countries have shown that students are positive towards the lecturer’s use of this technology. This includes mathematics
In fact, when mathematics lectures were presented from a tablet PC, student performance improved [11, 15].

Despite enthusiastic reports that the single tablet PC model improves interaction between lecturer and students, which leads to active learning through participation and enquiry, this mode still focuses on the lecturer as the direct operator of the technology. While the lecturer may communicate with the most active students in a large lecture theatre, it is difficult to gauge how much all students have actually understood, and if they can transfer newly acquired skills and knowledge to solve problems. This is usually tested after class in assignments or tests, implying no immediate feedback loop for students and lecturers.

On the other hand, if students also have access to this technology, tablet PCs may promote all principles of good practice in undergraduate education [16]. A literature review, focusing on the impact of tablet technology on student learning, can be found in [17]. Peer critique and increased access to more worked problems were strong points reported [11] when facilitating shared student solutions to calculus problems. Through this approach, students also took ownership of their learning. Formative feedback that students received from each other and the lecturer was ‘the most significant improvement that affected learning’ [18]. An interesting student quote reported in [5] is ‘having immediate feedback on my work during class puts the material in my head, really reducing the amount of outside study time’.

A good overview of the relevant literature on student tablet PC use, including problem solution submission by students, may be found in [19]. DyKnow® synchronisation software was used by the lecturer to view students’ screens while they were working on problems, and also after submission of solutions. A student’s solution was shown anonymously, for example to discuss an incorrect (or a correct) approach to the solution. The authors observe that, ‘the impact of this activity is to give students an opportunity to practice their knowledge in class and receive immediate instructor feedback that can potentially correct and prevent errors that may occur in out-of-class assessment activities such as homework or projects’ [19].

Giving all students a tablet pen and the ability to contribute anonymously to the class discussion means that confidence in the correctness of the solution is no longer the driving force behind student contribution. All students are on an equal level. This approach offers students a completely different view, in contrast to the beautifully laid out solutions which they usually see in a lecture.

The motivation for our project was to establish if it is possible to benefit from the advantages of using tablet technology to engage students in active learning, during targeted test preparation sessions, offered once or twice per semester, in a shared teaching space equipped with networked tablet technology for students but not available on a weekly basis.

3. Method

The test revision sessions in first year mathematics courses are usually offered in traditional large lecture theatres where the lecturer solves problems in front of the class. At one Australian university, these sessions were held in a new teaching space equipped with a pen-enabled screen for each student.
3.1 The teaching space

In line with investments by other Australian universities in technology-enhanced learning spaces [20], the University of Queensland refurbished a lecture theatre to build ACTS, the Advanced Concepts Teaching Space. This 100 fixed seat lecture room is equipped with a pen-enabled screen for each student. ACTS is first and foremost an experimental space, ‘in which it should be possible to effectively implement, and competently evaluate, as many new ideas as possible in teaching technology’ [21]. Secondly, the room opens ‘extra channels of communication’ along the three axes: Between teachers and students, among students, and between students and their learning material, with the objective to foster active learning as much as possible. Since ‘teacher-led instruction […] remains a crucial and much-used pedagogy’ [21], the room was set up like a lecture theatre. Three projectors were installed in the ceiling to project three different input sources simultaneously. SynchronEyes® synchronisation software was installed on all computers.

(Figure 1 goes here) – Figure 1 deleted

3.2 The Context

The impact of pen screen technology on learning was studied in the context of a level one multivariable calculus mathematics course. This course is taken by first year science and engineering students. For approximately half the cohort of 240 students, it was the first mathematics course taken at university, another quarter were repeating the course, while the remaining students had experienced other university mathematics courses. The course was taught over 13 weeks with compulsory weekly teaching sessions including three hours of traditional lectures, a one hour tutorial and a one hour computing session, introducing students to a computer algebra system. The assessment for the course comprised of six short answer assignments (24%), a forty-five minute mid semester examination (16%) and a two hour final examination (60%). In the lead up to both the mid semester and the final examination, revision sessions were usually held in a lecture environment. In these revision sessions, the lecturer often demonstrated the solutions of questions on a practice examination paper, and invited questions from students. The lecturer was conscious that interacting with students took extra time at the expense of not covering all material.

3.3 The revision sessions

In the first semester of 2010 and 2011, spanning from March till June, two 90 minute revision sessions were held in ACTS. These sessions were offered in ACTS to promote active learning, encourage peer learning and review, and facilitate immediate feedback to create a feedback loop. This required a rethinking of the pedagogy, as this student-centred approach takes control away from the lecturer. At the same time it allows for increased student (inter-) action in the classroom.

To ensure that the students were not distracted by the technology and could gain maximum benefit from these sessions, care was taken to structure the exercises. For example, students were to acquire the skills necessary for using the room while still learning course material. This was achieved by beginning the session with a simple task where the students were asked to answer multiple choice questions by writing on their screen ‘true’ or ‘false’. They also wrote brief solutions to simple revision questions already distributed in class. The lecturer presented answers to these by writing on a
tablet PC and projecting to the front screen. This established exemplars for the students indicating the sort of reasoning which was being elicited. It additionally emphasised the use of techniques such as visual reasoning to explore problem solutions.

Once students were up to speed with the technology, a PowerPoint presentation, containing a number of mathematical problems, was sent to all students. Students were encouraged to write solutions to each question on their slides, demonstrating their approach to problem solving. The lecturer then selected a suitable screen from the thumbnail overview presented by SynchronEyes®. This was displayed on the front screen for everyone to see.

Emphasis in the ensuing discussion was placed on the justification of solutions, see Figure 2 for a student exemplar which demonstrated the use of visual aides in presenting a solution.

(Figure 2 goes here)
Figure 2: A student visualises the situation before solving the problem in the 2011 class.

While the lecturer discussed the solution with all students, the individual producer of the solution remained anonymous, but at the same time was encouraged and was willing to interact by annotating and correcting solutions. At this stage reciprocity and cooperation were observed, with many students sharing in this process and updating solutions (as observed by the thumbnail displays).

Then, to emphasise the importance of rigorous analysis and logical presentation, students marked given partial solutions to questions. The partial solutions not only contained errors, which required identification and correction, they also lacked detail (see Figure 3). By displaying student responses the importance of including information such as definitions was highlighted. In the discussions about the marking it became clear to students that they could only receive marks if evidence of knowledge was presented.

(Figure 3 goes here)
Figure 3: Students are marking given partial solutions of potential test questions

A student solution that displayed all characteristics the lecturer was soliciting is displayed in Figure 4. The lecturer shared this solution with all students. She described its clarity as follows:

If I was marking this question the important features which demonstrate the mathematical ability of this student are as follows:
The student has identified the important information in the question (equations to plane) and labelled. They have then made the connection to planes and their normals, reworked the problem so that it was in terms of vectors and not algebraic equations to a plane. This allowed them to use their knowledge of linear algebra to help solve the problem. They have provided structure by analysing the solution in three cases, parallel, perpendicular and neither. In each case they state the theoretical condition which needs to be satisfied to meet this classification, then they test by substituting specific information into the general forms. Upon completion of all three cases they have their solution.
More difficult questions were reviewed towards the end of the session when students’ partial results were projected onto the front screen. This engaged students at all levels of competency. An individual’s attempts at partial solutions were projected onto the front screen to encourage both peer learning and peer review. This facilitated a discussion of strategies for moving through impasses. For instance, a screen was displayed where the student had not written anything to solve the problem. Starting with this blank screen a discussion of initial steps took place, for example collecting and writing relevant information, such as definitions, theorems and threads to other work. The selected, anonymous student was invited to enter this information onto their screen. This occurred across most blank screens, not only the anonymous one being projected. As part of this process students were also directed back to their notes to find and check the accuracy of their information. Once definitions, theorems and generic information was captured on their screen, some students made the leap to take the specific information and substitute it into the general form. By encouraging the students to work and rework information and maybe work backwards, strategies for problem solving were developed. Not all students needed prompting. Complete solutions were also displayed, sometimes to identify and correct small errors. This allowed for discussion of strategies for identifying errors. And finally, exemplary solutions with no mistakes were also acknowledged, as were different approaches, and this lead to a discussion of the value and connections between these.

3.4 Data collection
A multi-method approach to data collection was taken: Both quantitative and qualitative student feedback was collected after the mid-semester sessions. Student attendance at the sessions was recorded, researcher observations were audio recorded and transcribed immediately after the sessions. Handwritten notes on observations were taken during the sessions. Informal student feedback, in oral form as well as via email, was collected.

4. Results
In both 2010 and 2011, about 110 students attended one of two voluntary repeat mid-semester test preparation sessions. In both years, students filled in survey forms after the revision sessions. Figure 5 shows how students responded to some of these questions. Unsolicited feedback was also received via email.

More than 80% of the students in 2011 responded that they thought they had learned more in the ACTS session than they would have in a normal classroom. One student even commented ‘I really felt I learnt something today’. The session was rated as ‘good’ or ‘excellent’ by 84% of the students.

Students were also encouraged to write comments. A thematic analysis of the responses resulted in the four main categories of active learning, peer learning, prompt feedback and change in confidence. In reading these responses it was striking how positive they were and how often students used action verbs to
describe their experiences. Our interpretations of these comments are summarised below, sorted into the four categories.

4.1 Active Learning

Students commented in the surveys that they felt that they were more engaged and actively participated in the learning process. Recurring student observations are that the sessions provided opportunities for ‘doing’, or ‘solving’, i.e. the act of solving problems themselves. The sessions were ‘interactive’, ‘engaging’, ‘fun’, ‘useful’, ‘cool’. The format ‘encourages participation’ and they were more ‘involved’. This choice of descriptors doesn’t usually match student views of large mathematics classes, let alone test preparation sessions. Students commented ‘I was working on problems not just copying notes. It made my brain work harder’, and ‘It was more engaging than the usual tutorials’. A student commented that he had had a long day, but the session kept him awake. He didn’t realise how tired he was until afterwards. Another reflected that he thought ‘the actual process of doing the revision session was more valuable than the notes that I took out of it’. Another said that he had found the session ‘more personal and stimulating’.

4.2 Peer learning and prompt feedback

Students appreciated the opportunity to observe other students solving problems, and to receive prompt feedback on misconceptions. This was evidenced by repeated phrases, such as, ‘see how others are answering the questions’, ‘immediate feedback’ and ‘sharing work’. A student commented ‘It was really helpful. It made me think that I need to concentrate on the exam to not to make small mistakes’. Another said ‘The idea of sharing work, and even having students show step by step on how to do questions would benefit not just the class but the individual student.’ Of course it was not possible to display every student’s screen, however this did not seem to matter as a student observed ‘I felt as if we were all being addressed at the same time, rather than in a traditional scenario where some would get help and [not] others.’

A student said ‘Lessons where I can immediately check my work against both other students and the lecturer are extremely valuable. If I don't understand the way [the lecturer] has done it, I can look at other student's solutions. Either way, I don't sit there wondering why I got something wrong.’ Another student said that he thought the lecturer ‘was also able to explain material a lot better’. The lecturer by contrast responded that ‘in fact, I didn’t actually give the explanations and answers, I worked with theirs’. This shows how powerful peer learning can be, when students explain their understanding to other students.

The prompt feedback on student understanding also benefited the lecturer. For instance while she had explained the concept of a partial derivative in lectures, with students nodding and acknowledging their understanding, it became obvious in the ACTS session that many could not actually find a partial derivative. This provided a feedback loop and encouraged the lecturer to explain again in a subsequent lecture.
4.3 Confidence

In 2011, students were asked if the session had led to more confidence before the test. More than 80% of the students responded yes. A student commented ‘It may have helped me be more confident about the exam especially because I was able to complete the exercises in an unfamiliar format, and working through the exercises as a class and viewing other students results and working helped me to understand and remember the processes’. Another said that receiving feedback on how well he was doing made him confident that he would do well on the test.

5. Discussion

In contrast to other studies [22] where students were easily side tracked when using tablet PCs in the classroom, students in our study were engaged with this new technology and its application to learning mathematics problem solving. In fact, there was none of the chatting that usually occurs in large classrooms. This may also have been because students could work ahead if they wanted as there was a sufficient number of problems to keep the better students working. In the 2010 survey, some students commented that the technology temporarily distracted them. Some said they were doodling, ‘I did doodle a little on the slides but completed all the questions.’ Another student wrote that ‘The use of the technology for me gave more attention to the task at hand.’

In addition, it appears that the technology facilitated a change in the relationship between students and lecturer, as the students felt more confident to ask questions. The lecturer commented that after the lecture following the test revision sessions in 2010, she ‘felt that the students were more positive towards me’. She had pointed out to the students in that lecture that they had to ask for help if they did not understand a concept. While this usually does not result in an increase in student queries, she ‘had like double or treble the amount of questions at the end of the lecture’.

Because of the time spent interacting with students and engaging the students in problem solving activities, only a fraction of the questions were covered in the ACTS sessions compared to usual test revision sessions. This did, however, not cause concern from lecturer or students, as emphasis was placed on learning problem solving strategies in general, and understanding what is meant by ‘show your working’.

While there was overwhelmingly positive feedback from students, the lecturer also benefited from these sessions as they enabled her to achieve what had been impossible before: to emphasise the principles of problem solving strategies, analytical thinking and logical presentation, and at the same time to work with students to implement these strategies straight away and to give immediate feedback. This reinforced these ideas and students appeared to understand the points she made.

Following our experiences in ACTS, we will propose an extension to Kowalski, Kowalski and Gardner’s recommendations [8] for in-class exercises. We suggest that in the mathematics context, they should also

- give an opportunity to explore different paths, thereby encouraging individual thinking for enhanced problem solving as distinct from repetition from memory;
- address ‘stuck places’ or ‘impasses’ in problem solving or ‘thresholds’ key concepts students typically struggle to understand;
encourage students to take part in the problem construction process by exploring how to increase the level of difficulty of a question.

6. Conclusion
We have shown that educational technologies deployed in test preparation sessions can engage first year mathematics students in active learning. In the two years when pen-enabled screen sessions were offered in a multivariable calculus course, the experience has been rewarding for all involved and the feedback from students has been impressive. To summarise the main advantages of the technology: It initiated students’ development of strategies to overcome impasses, it allowed students to rank themselves among their peers, and it enabled them to see attributes of the solution to a mathematical problem from the point of view of a marker for the first time.

Our study differs from others as tablet technology was used in a focused way for test and examination preparation sessions, rather than on a regular basis throughout the semester. We were also dealing with large classes, where interaction may be more difficult to achieve than in small classes. Despite offered on a voluntary basis, a large number of students participated. While not many universities will have access to the particular technologies available in the ACTS lab, we emphasise that similar outcomes could be achieved with alternative setups such as 1) equipping already existing computers with graphics tablets, 2) moving away from desktop technology altogether by equipping a room with one of the many emerging models of affordable tablets with pen or finger touch input, and finally 3) by providing a tablet input device for groups of two or three students rather than individually, which would lead to collaboration not just at the classroom level, but also at small group level and reduce costs.

The purpose of this paper was to demonstrate how active learning can be achieved, and how students felt about our approach. Future work will focus on the impact these sessions have on test and examination performance for students who attended. It is also planned to give students a mathematical problem, and ask the better students to increase its difficulty, followed by discussion. This then places all students in the position of the person setting exam questions. On a follow up study, we will match revision questions with exam questions and evaluate if students who attended the revision sessions make fewer of the common mistakes than those who did not attend.

References
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The length $L$, width $W$ and height $H$ of a box of height $H$ are changing with time. At a certain instant the dimensions are $L=1$ m and $W=1=2$ m, $L$ and $W$ are increasing at a rate of 2 m/s while $H$ is decreasing at a rate of 3 m/s. At that instant find the rate of change of the surface area of the box.

\[
S = 2LW + 2LH + 2WH
\]

\[
\frac{dS}{dt} = \frac{d}{dt}[2LW] + \frac{d}{dt}[2LH] + \frac{d}{dt}[2WH] \\
= 2\frac{d}{dt}[LW] + 2\frac{d}{dt}[LH] + 2\frac{d}{dt}[WH] \\
= 2[L\frac{d}{dt}[W]] + 2[L\frac{d}{dt}[H]] + 2[W\frac{d}{dt}[L]] + 2[H\frac{d}{dt}[W]] + 2[H\frac{d}{dt}[W]] + 2[H\frac{d}{dt}[H]] \\
= 2[L\cdot2 + W\cdot2] + 2[L\cdot3 + H\cdot3] + 2[W\cdot2 + H\cdot3] \\
= 4L + 4W + 6L + 6H + 4W + 3H \\
= 10L + 10W + 9H - 10 = 18 \text{ m}^2/s
\]

Figure 2: A student visualises the situation before solving the problem in the 2011 class.

Consider the surface $z = f(x, y) = e^x y^2$.

Find the tangent plane to $f(x, y)$ at $(2, 1)$.

$z = e^x (x + 2y - 4)$

$\frac{\partial z}{\partial x} = e^x (x + 2y)$

$\frac{\partial z}{\partial y} = 2e^x y$  \hspace{1cm} 2 marks

Consider the surface $z = f(x, y) = e^x y^2$.

What is the normal to this plane.

$\vec{z} = e^x (x + 2y - 4)$

$\vec{n} = e^x \hat{i} + 2e^x \hat{j} - \hat{k}$

Figure 3: Students are marking given partial solutions of potential test questions.
Figure 4: An exemplar solution created by a student
2011: Did you learn more in the ACTS lab session than you would have in a normal classroom? (n=87)

2011: How would you rate the value of this session? (n=84)

2010: Did you find the ACTs lab session more engaging and interesting than other classes? (n=31)

2010: Would you attend if voluntary revision classes were offered before the final exam in the ACTs lab? (n=46)

Figure 5: An overview of students’ responses to formal surveys