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IMPROVING STUDENT ENGAGEMENT IN MATHEMATICS USING SIMPLE BUT EFFECTIVE METHODS

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Abstract

A significant proportion of students enrolling in mathematical subjects designed for non-STEM majors in university courses have minimal mathematical skills and poor motivation. This combination of starting attributes often leads to failure in the first mathematical subject encountered. We have been implementing simple, alternative pedagogies in an attempt to improve student performance in one such first-year subject.

The failure rate in this first-year algebra-based mathematics compulsory service subject in a non-STEM discipline has been consistently high, despite many supportive resources being available. Anecdotal evidence suggested that it was students' lack of engagement with all aspects of the subject that accounted for the lack of use of these support mechanisms.

Last year, a major change to teaching practice was introduced. Workshops have replaced tutorials with the tutor becoming a facilitator. Problems given are graded in difficulty, allowing students to work at their level. Students' expectations were also discussed and compared to the results of previous cohorts. Different strategies were then put in place with the aim of motivating students to engage with the subject.

In this study, results indicating an improvement in student engagement were based on comparing tutorial attendance rates, performance in assessment items and attendance rates in optional support sessions over several years.

Introduction

Mathematics is becoming increasingly important in many areas including science, engineering, business and IT. "There is a global perception that a workforce with a substantial proportion educated in Mathematics, Engineering and Science (MES) is essential to future prosperity" (Chubb, 2012, p. 6). Yet mathematics in Australia is not in a good state: "… the state of the mathematical sciences and related quantitative disciplines in Australia has deteriorated to a dangerous level, and continues to deteriorate" (Brown, 2009, p. 3). This is exacerbated by the fact that lower levels of mathematics are increasingly being taken by secondary school students (Chubb, 2012, pp. 19, 20). With universities opening their doors to more students as the government aims to raise the percentage of Australian 25 to 34 year olds with a bachelor's qualification to 40 per cent, academics teaching mathematics at tertiary institutions in Australia are facing a huge challenge. Many students enter university with a poor mathematics background which leads often to failure in first year mathematics subjects (Rylands & Coady, 2009). Universities must do all they can to raise the level of mathematics in students.

Many degree programs in Australia assume that students have some knowledge of mathematics beyond the basics. However, this is not widely published with many courses not stating any assumed knowledge let alone prerequisite knowledge in mathematics. While some might consider it misleading not to at least state some assumed mathematical knowledge, this is common in the Australian higher education system. Mathematics is seen by some as driving students away and so in the competitive higher education system, removing mathematics as a prerequisite or assumed knowledge is one way of boosting intake, and hence income. For example, a recent survey of 17 Australian universities

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discovered that seven had mathematics as a prerequisite for a bachelor of science, five listed mathematics as assumed knowledge and five had neither (Belward et al., 2011).

Mathematics academics are often faced with poorly prepared students, many of whom do not like or know how to learn mathematics. Yet to succeed students must do mathematics: “The underlying principle is simple: Students learn math by doing math, not by listening to someone talk about doing math” (Twigg, 2011, p. 26).

Twigg (2011) presents a model for mathematics subject design for tertiary institutions that has involved 37 institutions over 11 years. The model considers the advantages of the capabilities of information technology, however the four core principles given for the success of the model are not dependent on technology. These core principles are:

- Students spend the bulk of their time doing math problems;
- Students spend more time on things they don’t understand and less time on things they have already mastered;
- Students get assistance when they encounter problems;
- Students are required to do math.

Motivation alone for many first year mathematics students appears not to be enough to get them to do mathematics. Our staff see some weak but very, very motivated students, for example, those for whom the mathematics subject stands between them and graduation. Yet in such students we sometimes discover that they do little or no work outside class and never get assistance when they encounter problems. The experience of our staff suggests that Twigg (2011, p. 25) is correct when she writes “The primary reason many students do not succeed … is that they do not actually do the problems.”

In our institution, it is difficult to make changes to delivery methods without a lengthy formal approval process. The minor changes discussed in this paper did not require formal approval and so could be implemented immediately.

The simple and easy to implement strategies presented produced immediate positive results in a first year first semester mathematics service subject. We will refer to this mathematics service subject as just the subject. The university in which this runs is a large multi-campus metropolitan university in Australia; the subject is for students who are not enrolled in a STEM (science, technology, engineering, and mathematics) degree. We consider the offerings of the subject on only one campus as it has run on that campus for some years with enrolment of about 100 students each semester, and over that time the cohort consisted mostly of students enrolled in one non STEM area. Most of these students are not intending to take further mathematics; in fact many did not expect to have to take any mathematics at university. The degree programs into which they enrolled do not have mathematics as a prerequisite or as assumed knowledge. A large proportion of students enrolled in the subject have a poor mathematics background, some suffer from mathematics anxiety and have no confidence in their mathematical ability. The subject revises early to middle secondary school mathematics, covers algebra, graphs (mostly linear) and moves on to functions (including exponentials and logarithms), some statistics and early calculus.

In 2010 almost 60% of students who completed the whole semester including the final examination failed. A large number of students began the subject but did not complete it; if they are included in the total then the failure rate was 63%. The failure rate had been similar or worse for several years. The poorly prepared students are at a much, much greater risk of failing than those with good mathematics background.

Methodology

Students in the subject were classified as being in one of three groups based on their mathematics

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background. We had information on the mathematics background of a large proportion of our students; those who completed secondary education in the last decade in our state. Barrington and Brown (2005) classify secondary school Australian mathematics subjects as Elementary, Intermediate and Advanced. Advanced subjects are for students who need very good mathematical preparation for tertiary studies in mathematics, engineering and similar. Intermediate subjects are for students who need some mathematics for tertiary studies in areas such as science, agriculture and dentistry; most Intermediate subjects include differential and integral calculus. Elementary subjects are suitable for students who want to study some mathematics but who do not need mathematics for tertiary study in areas such as those which require Intermediate mathematics.

There were almost no students with an Advanced mathematics background enrolled in the subject, so they have been included with those who have an Intermediate background. The three groups of students used for this study are

- The *Elementary group*: Those who completed Elementary mathematics in secondary school;
- The *Intermediate group:* Those who completed Intermediate mathematics or higher in secondary school;
- *Group 3:* Those for whom we have no information on background (that is, did not complete secondary school mathematics in our state in the last decade).

The proportion of students in each of the three groups is given in Table 1.

Table 1. The percentage of students in each of the three groups.

	2010	**2011**	**2012**
Elementary group	59%	61%	44%
Intermediate group	27%	21%	31%
Group 3	14%	18%	25%

It has been shown (Rylands & Coady, 2009) that students with an Elementary mathematics background perform much worse than those with an Intermediate background in some first year first semester tertiary mathematics subjects. This is the case here as is shown in Table 2. Hence most of the analysis presented in this paper will treat the three groups separately. For Group 3 we have no information on the students as a group, although we do know from individual contact with a few of these students that their backgrounds vary enormously, from having completed secondary education several decades ago with no mathematics in their final two years to having completed high level tertiary mathematics subjects. Hence for some of the group analyses Group 3 will be omitted.

Extracurricular support has been offered to students, sometimes peer mentored study sessions, sometimes sessions run by specialist mathematics support staff and sometimes both. The amount and type of this support has varied from year to year.

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Table 2. Failure rates for 2010 and 2011; including those who discontinued the subject during semester.

	2010	**2011**
Elementary group	87%	72%
Intermediate group	9%	18%
Group 3	56%	40%

Extracurricular support has been offered to students, sometimes peer mentored study sessions, sometimes sessions run by specialist mathematics support staff and sometimes both. The amount and type of this support has varied from year to year.

Over the three years from 2010 to 2012 the content of the subject has not changed. In 2012 the emphasis of the latter third of the course and the order in which this was delivered changed. Therefore the early assessment items can be compared from year to year, however, the later assessments were too different for any meaningful comparison to be made.

The subject has three tests during the semester and a final examination at the end of the semester. Over three years, 2010 to 2012, we collected all test and examination marks. Attendance at the weekly tutorials for 2011 and 2012 and attendance at support sessions for 2011 and 2012 was also collected. This data was merged with the mathematics background data. Attendance data for 2010 was not available.

Test 1 is held early in the semester and covers only revision of elementary mathematical concepts which were covered the first two weeks of semester. This is revision of early to middle secondary school mathematics and so the greatest influence on the results of Test 1 is the skills students have when they enter the subject. Test 1 contributes 10% to the final mark in the subject. Test 2 is held later in the semester and covers the material presented in the first half of the semester. Test 3 results are not used here as the material in the subject was reorganised in 2012 and so while the topics examined in Tests 1 and 2 were unchanged, Test 3 covered different topics to the previous years. Tests 2 and 3 contribute 15% each to the final mark.

Interventions aimed at improvement

In an effort to improve engagement and performance staff made two changes to the subject:

- At the beginning of the semester, students were asked about their expectations in relation to their final grade. All students indicated that they expected to pass. A discussion then took place in relation to these expectations, based on the experiences of similar cohorts in past years, which included alerting students to the failure rate of previous cohorts (around 50%). Strategies to prevent the same happening again were then discussed with the group. Students were frequently reminded throughout the semester about the strategies discussed in the first lecture, in an effort to keep students focussed on procedures needed to achieve success in the subject.
- The common mathematics style tutorial where the tutor spends a considerable amount of time or all the time talking to the group as a whole was replaced by a workshop style tutorial in which the tutor became a facilitator, did not give presentations to the class as a whole and instead facilitated small group or individual work. Students were encouraged to choose problems from a list of graded questions. The facilitator actively assisted the groups with their work by focussing their attention on the task/s at hand.

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The first intervention appears at first sight to be rather confrontational. However, attempts in previous years to deliver a similar but more gentle message make no measurable difference to students' behaviour or performance. Several years ago a short written survey run in the first class of semester indicated that all students expected to pass. In 2010 and 2011 students were shown a graph of expectations versus final grades for the students surveyed, but only for those who received passing grades. This showed that in the past students gained, generally, one or two grades lower than expected. The graph also indicated that many students failed the subject, though numbers were not given. This appeared to make no difference to students' attitudes to the subject and no difference to performance. The failure of a gentle message to penetrate made staff decide to try a more direct approach.

Mathematics tutorials often have the tutor talking to the group for some or all of the time. It is difficult to engage students in the work, especially for those in a non-STEM degree. In this situation the temptation to give up on getting students to work and think for themselves is overwhelming; the easy way out is just to show students how to do problems rather than persist in getting the students to struggle with the mathematics. The second intervention came about because staff felt, and anecdotal evidence confirmed, that many students spent little or no time on mathematics outside class. We also suspected that some students did not know how to start a mathematics problem or would not persist if stuck. So we used what time we had available in class, the tutorials, to get students to do mathematics.

Results

The first of the three semester tests, Test 1, examines basic mathematics which has been briefly revised in the first two weeks of semester. There was no significant difference in marks for this test before and after the implementation of either of the interventions described in the previous section. There was no statistically significant difference in the background of the students from 2010 to 2012 (p=0.07) and entry requirements had remained stable across those three years. Consequently, we consider Test 1 to be a good measure of student background.

A second test, Test 2, held at the mid semester point, however, showed some differences across the three years. Two sample t tests show significant differences between the results for 2010 and 2011 and between 2010 and 2012, but no significant change between 2011 and 2012. That is, improvement in Test 2 results appeared after the implementation of the workshop style tutorials. In 2012, after students compared their expectations for the subject with reality, there was a significant increase in support workshop attendance. The percentage of students attending at least one optional support sessions was 27%, perhaps too small to show a significant improvement for the cohort overall in Test 2. The most noticeable improvement was a significant improvement (p=0.0009) in Test 2 results from 2010 to 2012.

The next two subsections look at the results in more detail and concentrate on the Elementary group.

Improved tutorial participation

To establish that changing to workshop style tutorials improved student performance we first need to consider attendance data. External motivation in the form of recording attendance was provided to encourage tutorial attendance in 2010-12. Attendance is always good (around 75% across the whole semester) as students do not like to be recorded as absent even though marks were not given for tutorial attendance. When considering the effect of the workshop style tutorials on student performance, tutorial attendance up to Test 2 (over 85% for the whole class) is used when considering possible improvement in Test 2 marks. For the Intermediate group in 2011 and 2012 attendance was excellent with over 80% attending all tutorials. There was such a small variation in attendance there was nothing to be gained by calculating the correlation between tutorial attendance and Test 2 marks for Intermediate students. Tutorial attendance in 2011 and 2012 did not differ significantly. Staff recalled that in 2010 attendance dropped off gradually after the first few weeks.

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As stated above there was a statistically significant improvement in Test 2 marks between years 2010 to 2012 for the whole cohort. However, the biggest gains, in terms of passing grades, are to be made with the weaker students, that is, those in the Elementary group and the weak students in Group 3. Mean marks for Tests 1 and 2 for the Elementary and Intermediate groups are shown in Table 3.

Table 3. Mean results for Tests 1 and 2.

	Elementary Group			Intermediate Group		
	2010	**2011**	**2012**	**2010**	**2011**	**2012**
Test 1	68%	71%	70%	93%	91%	89%
Test 2	24%	38%	35%	73%	78%	80%

For the Elementary students there was a statistically significant improvement in mean Test 2 results from 2010 to 2011 (p=0.000032), a statistically significant improvement from 2010 to 2012 (p=0.0018) and no significant difference between 2011 and 2012. In this group, the one for which lifting performance is most important, there were significant improvements in performance, which is expected to flow through to better performance overall in the subject and hence better retention rates. Group 3, for which we had no data on mathematics background, includes some very weak students. It is possible that they also gained from the implementation of workshop style tutorials.

The benefit to the Elementary students of tutorial attendance is shown by consideration of the relationship between the marks obtained in the first two tests and tutorial attendance. The correlation between tutorial attendance and Test 1 in 2012 was not significant and not surprising as Test 1 is more influenced by mathematical background. The correlation between tutorial attendance up until Test 2 and Test 2 marks was 0.42, which is statistically significant (p=0.02). This indicates that there was a benefit of the workshop style tutorials to Elementary group students. The means for Test 1 are high because the test is easy for most students; a mark lower than 80% indicates that the student has a very weak mathematical background. A final combined mark of at least 50 per cent is required to pass the subject. Although the Test 1 marks are high they have little effect on the final mark for the subject because they contribute only 10 per cent to the total mark. The marks for Test 2 illustrate the enormous difference in performance between the Elementary and Intermediate groups.

Test 3 marks and the final examination marks are not radically different to the Test 2 marks, so Table 3 shows very clearly that to improve the overall pass rate for the subject it is Elementary group students rather than Intermediate group students who need to increase their performance.

It should be noted that the tutors/facilitators for the workshop style tutorials were very experienced at working with secondary school and first year university students and had no trouble facilitating the workshop style tutorials.

Improved participation in extracurricular support

In 2010 and 2011 peer support sessions ran once a week and support sessions were run by mathematics support staff. Attendance at the peer support sessions was very poor with an average of approximately one student per session. Hence peer support sessions were not organised for 2012. Because of poor attendance at the support sessions in 2010 and no requests for extra sessions there was one pre-test support session in 2011 which was attended by four students. No further support sessions were run in2011 and none were requested.

In 2012, even though there were no peer support sessions offered, no support sessions had been planned. This was a result of the very low interest in extracurricular support in the previous few years.

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After the first lecture many requests for extra support, assistance and advice were received and such requests continued throughout the semester. As a result two support sessions a week were scheduled. The average session attendance was between seven and eight until Test 3, after which it dropped off a little.

Roughly a quarter of the students enrolled in the subject attended at least one support session. Of these, 89% completed the three tests during semester. This was an excellent outcome.

The performance of Intermediate and Group 3 students attending support sessions is not considered here as the numbers of these students was very small.

Students with Elementary mathematics backgrounds made up 60% of those who attended at least one support session. The mean test marks for this subgroup of Elementary students is compared with those of the whole Elementary group in Table 4. Comparing individual improvements by students between Test 1 and Test 2 did not show a statistically significant (p=0.08) improvement for those who made use of the support sessions. However there appears to be a greater improvement for those who undertook the workshops but this needs to be tested on a larger group of students.

Table 4. 2012: Mean test marks of Elementary group students who attended support sessions vs the Elementary group as a whole.

	At least one support session	**All students**
Test 1	67%	70%
Test 2	38%	35%

There was no statistically significant increase in Test 2 marks for all 2012 students compared with the 2011 cohort. An increase might have been expected because the support sessions could have lifted marks enough to be significant. One possibility is that an increase was not seen because the number of students who attended the support sessions was too small.

Conclusion

The changes in teaching practice produced significant results by the middle of semester. These changes were cost effective, simple to implement and did not require significant time for planning or implementation. The improvements increased student involvement with subject content through the tutorial workshops and/or improved student motivation and engagement with extracurricular support.

The facilitated workshop style tutorials and take up of extracurricular support sessions goes towards satisfying Twigg's (2011) four core principles. Students in the unit were doing more mathematics, they were encouraged to work on appropriate problems for their level and there was a facilitator to assist those in trouble. Students were doing more of the problems and as a result they were doing more mathematics. The workshop style tutorials were only one hour long, so there is much scope for more improvement and further movement towards Twigg's model.

The increased interest in and use of support services is a positive change. Our numbers were not large enough to determine whether or not those who made use of these services did improve, but it is likely that their performance did improve as their engagement with the subject matter increased.

The improvement in student performance was significant, yet small. The Elementary group students were not well prepared for university mathematics and staff know from experience that some of these students dislike mathematics. Kajander and Lovric (2005, p. 157) state

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> "Furthermore, it is very difficult, in university, to make up for an inadequate high school experience. High school really matters because it gives students an opportunity to better develop a variety of mathematics-related skills over longer periods of time in small groups."

Kajander and Lovric (2005) go on to say that there is a correlation between positive experience in secondary school and good performance in university mathematics, and those with negative secondary school experiences do not fully recover, and end up with low to mediocre marks in university mathematics. While a large improvement in student performance would be ideal, in the light of these statements a small improvement in performance gained by using simple interventions is a huge step in the right direction.

Lack of data or circumstances prevented the study of various aspects of the interventions. This suggests directions for future research. Some of these aspects are:

- Comparisons across several semesters or years of a stable subject to determine what effect, if any, the interventions had on the final results and failure rates of the subject. We were unable to do this as the last third of the subject was rearranged.
- The effect of the interventions on retention rates. Did retentions rates improve?
- Staff recall that in 2010 tutorial attendance dropped off gradually after the first few weeks. Does the change in tutorial style affect attendance, that is, are workshop style tutorials better attended?
- The effectiveness of these interventions with inexperienced facilitators, for example, postgraduate students.

The problem of getting poorly prepared students up to the standard required for passing in first year tertiary mathematics will become greater in Australia over the next few years as the planned growth in undergraduate students results in larger first year classes. Therefore there is much to be gained by testing such interventions again more thoroughly, and refining them to maximize the gains. Financial constraints, increasing student numbers and the consequent stress on resources make fast, easy and cost effective changes extremely attractive and practical.

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