Do lower entry-level students benefit most from engagement-centered teaching in a compulsory first year mathematics subject?

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Abstract

In Australian universities there has been increase in the proportion of students entering with low numerical skills. Yet, science disciplines require increasingly sophisticated mathematical and computational methods. This misalignment is especially challenging in highly diverse student cohorts. We investigated how an engagement-focused delivery of a first year quantitative skills subject altered (i) students' affective attributes, (ii) their appraisal of their own learning and (iii) how these measures related to student achievement for lower and higher entry-level student groups. We found no change between the start and the end of semester in students' affective attributes. Further, our results (i) suggest that students improved their judgement of their understanding and skills by the end of the semester and (ii) encourage ongoing development and evaluation of engagement-focused teaching strategies to lift the performance of lower entry-level students.

Introduction

First year students' range of preparedness for university level mathematics is huge (Varsavsky, 2010). In Australia the relaxation of entrance requirements (Norton, 2015) is occurring simultaneously with an increasing lack of interest in and engagement with mathematics (Barton and Sheryn, 2010), while disciplines of both the natural and social sciences increasingly require mathematics. The avoidance of subjects, courses and careers that involve mathematics not only limits students' future opportunities and career pathways (Buckley, 2013) but affects national productivity and competiveness (Erickson & Heit, 2013). For these reasons students' disengagement with mathematics is a concern in Australia and several other OECD countries (Rice, Thomas, O'Toole & Pannizon, 2009; Varsavsky, 2010; West, 2012; Matthews, Hodgson & Varsavsky, 2013).

Under-preparedness and lack of engagement presents a problem not only for students but also for academic staff who find significant gaps between assumptions that academic staff have of students' knowledge, preparedness and students' actual knowledge. In response to this widening gap, many universities have introduced multiple pathways to develop the required quantitative skills to meet graduate outcomes of various science degree programs. Many universities have introduced diagnostic testing to streamline students into mathematics subjects requiring different levels of preparedness, to assist students with remedial programs, or as a research tool to predict student success in first year mathematics (Cox, 2001; Tariq, 2003). These interventions appear to have limited success as up to a quarter of students in first year preparatory courses of a leading metropolitan university fail and subsequently completely disengage with mathematics (Varsavsky, 2010). Diagnostic testing identifies weaknesses in students' knowledge but it does not help to address students' negative emotions that are seen as contributing to students' avoidance of and disengagement with mathematics (Pekrun & Linnenbrink-Garcia, 2012).

Economies of scale also curtail the ability of small to medium-sized universities to offer multiple pathways to facilitate the attainment of quantitative skills that meet the threshold learning outcomes (TLOs) of Australian graduates of bachelor level degrees in science disciplines (Jones, Yates, & Kelder, 2012). Instead, universities with a relatively small cohort of first year science students are limited to single-stream, first year mathematics classes to prepare students for level two and three studies within the various disciplines. By necessity, in such common first year mathematics subjects, student diversity is large and spanning multiple dimensions including mathematical backgrounds, general academic ability, disciplinary interests, language, family exposure to university and socioeconomic status. The defining challenge for staff designing and teaching level one mathematics to such highly diverse student bodies is to create learning environments that foster positive emotions and maximize student engagement with quantitative problem solving – a defining skill for science disciplines.

Closing the widening gap between what students are expected to know (the assumed conceptual and procedural knowledge), and what they actually know (conceptual and procedural knowledge revealed by diagnostic tests) has been the focus of teaching first year mathematics at many universities. In contrast, little or no practical consideration has been given to understanding metacognitive and affective factors that influence student learning and to understand how different groups of students may respond to strategies designed to optimise those factors (Carini, Kuh & Klein, 2006; Pekrun & Linnenbrink-Garcia, 2012). Similarly, understanding what students *think* they know and how they judge their progress has profound implications on learning outcomes and attitudes to learning (Townsend & Heit, 2011; Erickson & Heit, 2013).

Previously we demonstrated that a student-centered and engagement-focused approach alleviated anxiety and increased mathematics confidence, in particular amongst non-mathematics majors and female students (Everingham, Gyuris & Sexton, 2013). Here, using new data, we examine the impact that such an approach to teaching quantitative skills to a first year, highly diverse cohort of students at a regional Australian University has on 1) students' non-cognitive affective attributes, including mathematical confidence and anxiety, 2) their appraisal or awareness of their own learning and 3) associated relationships with students' learning achievement.

Materials and methods

Situational context of our study

James Cook University is a mid-size, research-intensive institution with an annual intake of 200-250 students in 16 disciplinary majors studying for the Bachelor of Science. Commencing students are highly diverse with respect to numerous diversity indicators including the participation of key equity groups (Indigenous, 4.3%; low SES 20.9%; regional/remote, 23%), first-in-family to university, first language, age, as well as general academic ability (Queensland Tertiary Admissions Centre course cutoff in the 2013 offer rounds for the BSc was OP17/ATAR 64), mathematical background and disciplinary interests. In 2010 the university implemented its revised BSc program, with a compulsory, common, first year mathematics subject designed to enhance engagement with the quantitative skills required of scientists responding to the challenges of the 21st century. The BSc at James Cook requires the completion of 4SA of Mathematics B (that is, four semesters of intermediate mathematics with a minimum of satisfactory achievement) or its equivalent, or higher level mathematics. The interdisciplinary mathematical modelling subject titled "SC1102:03 Modelling Natural Systems" integrates the core elements of mathematics, computing and science. This subject was delivered as an integrated sequence of three case studies, each building a different but overlapping set of core competencies in mathematics and MS Excel. Since most students taking this subject were from the biological, earth and environmental sciences, it was the computing and mathematical components of the subject that were assumed to trigger the negative emotions that block the achievement of many students.

One explicit purpose of the subject was to alleviate the perceived difficulty, resulting in fear and anxiety, that is often associated with the learning and application of quantitative skills. Hence design and delivery of teaching and learning in this subject progressively focused on strategies for engagement (Everingham, Gyuris & Sexton, 2013) with the understanding that engaged students will be more likely to be shifted to positive activated emotional states (Pekrun & Linnenbrink-Garcia, 2012) and this in turn will manifest in higher levels of achievement as can be gauged by grades and retention (Kuh, 2001). Following the initial year of the subject's introduction, the engagement strategies deployed by the teaching team focused on strengthening cognitive-behavioural and social-behavioural engagement. The teaching interventions that were implemented included strategies to enable intensive and varied student-to-student, staff-to-student and staff-to-staff interactions; a variety of assessment and feedback strategies each with specific aims and objectives of enhancing goal-directed academic effort; provision of a learning advisor to assist, in an on-demand basis, with cognitive and metacognitive aspects of learning; development of relevant and contextualized learning experiences specifically linked to each assessment task; and provision of rich, technology-enabled learning support materials. The rationale, development and implementation of these strategies are detailed by Everingham, Gyuris & Sexton (2013).

Data collection

We surveyed students in the first and last week of the 13-week long second semester of the 2013 academic year. Using scales that have been previously described and validated (Hopko, Mahadevan, Bare & Hunt, 2003; Pierce, Stacey & Barkatsas, 2007; Lim, Tsob & Lin, 2009 and Everingham, Gyuris & Sexton, 2013) our questionnaire probed students' mathematical confidence (MC; nine items, such as "I always have the confidence to complete the mathematics in my assignments" and "I always find it easy to draw graphs to explain scientific phenomena"), mathematics learning anxiety (MLA; seven items, such as: "I feel anxious watching a teacher work an algebraic equation at the front of the class") and technology for learning mathematics (TL; six items, including "Using Microsoft Excel makes mathematical tasks more interesting"). Other questions (five items) sought demographic and enrolment information.

A further 13 questions were used to capture students' appraisal of their own understanding and skills. This was measured by students' self-reported ease with a selection of the subject's core competencies. These competencies were selected because they constituted tasks that frequently formed part of tutorial, assignment, test and exam questions, and, with the exception of the Excel based questions, formed part of the high school senior syllabus (see list below). While students were assumed to have some level of familiarity with these procedures and topics, the subject was designed to teach, practise and develop them further. Using a 5-point Likert scale (with 1 being 'very easy' and 5 being 'very difficult') we asked students to indicate, "How difficult are the following topics for you?". A "No idea/ have not done it before" option was also provided:

1. Entering data into an Excel sheet
2. Drawing graphs in an Excel sheet
3. Scientific notation for numbers
4. Calculating the standard deviation
5. Describing the relationship between an x variable and a y variable
6. Interpreting a correlation coefficient
7. Plotting the linear equation $y = 2x + 3$ by hand
8. Plotting the quadratic equation $y = 10 - 5x^2$
9. Geometric growth curves
10. Solving a mathematical equation for x
11. Manipulating a mathematical equation
12. Deriving a mathematical equation
13. Numerical, visual and conceptual characterizations of a system

It is important to note that the questionnaire did not ask students to perform any tasks – it was not a diagnostic test – nor did it ask students to estimate their own ability relative to that of others. The questionnaire simply asked students to rate the ease or difficulty they had with these topics in week 1 and again in week 13. The "No idea" option was important as it indicated that the student did not encounter the topic, did not recall an encounter or simply did not recognise the topic at all. Student achievement was taken as the students' final weighted average score over all assessment items, expressed on a percentage scale 0-100. Students' Overall Position (OP) or corresponding Australian Tertiary Admission Rank (ATAR) were obtained from the university's records.

Data analysis

From the responses to the 13 topics above, we created three indices: the "Easy" index, the "Difficult" index and the "No Idea" index each ranging between 0-13. The Easy index was measured by the number of topics that a student indicated were either very easy or easy (responding with a 1 or 2). The Difficult index was measured by the number of topics that the student indicated were either difficult or very difficult (responding with a 4 or 5). The No Idea index gave a measure of the number of topics for which a student selected the "No idea/have not done it before" option.

Paired sign tests were used to compare affective attributes (MC, MLA and TC), and the Easy, Difficult and No idea indices obtained, for each student, at week 1 and week 13. Two sided p-values are reported and swings in negative and positive directions are reported descriptively. Spearman's rank correlation was used to compute the correlation between the attitudinal and task driven indices and students' final mark. Two sided p-values are reported and negative and positive values of the correlation are reported descriptively. Regressions were fitted to the significant correlates of final mark to determine if this relationship was impacted by the tertiary entrance level of students. Here, a dummy variable was created to indicate high (defined as those with an OP 1-10 or ATAR $\geq$ 80) and low level (defined as those with an OP 11-24 or ATAR < 80) entry students. We arbitrarily chose this cutoff as students with an OP 1-10 represented approximately 50% of the OP eligible population of students in Queensland in 2013. The regressions had final mark as the dependent variable. The independent variables were the significant correlate, the dummy indicator variable and interaction between the dummy variable and the correlate. Two sided p-values for testing the significance of regression coefficients are provided and the model is presented visually with the aid of scatterplots and lines of best fit.

Results: students' affective attributes, their self-appraisal of learning and their achievement

Eighty-four students returned usable surveys from both the start and end of semester giving a response rate 35.3%. The overwhelming majority (n=77) planned to major in one of the biological or earth and environmental science disciplines while the remaining seven students were enrolled in mathematics and/or physics majors.

The surveys did not display significant changes between week 1 and week 13 in mathematical confidence, mathematics learning anxiety and technology for learning mathematics. Students displayed much variation in how they appraised their understanding and skills in the thirteen topics that were amongst the core competencies for the subject (Figure 1). Aggregating this information across all topics, the No idea index decreased across the semester ($p<0.0005$), the Difficult index did not change ($p>0.999$) and the Easy index increased ($p=0.002$). Although no formal statistical tests were performed, the proportion of "Easy" responses to topics 11, 12 and 13 did not follow this trend. "Easy" responses to these topics were higher in week 1 than in week 13 (Figure 1). The improvement in response to perceived mastery of Excel (topics 1 and 2) and geometric curves (topic 9) are noteworthy.

Using Spearman's rho, the Easy index correlated positively with mathematical confidence and negatively with mathematics learning anxiety in both week 1 (MC: $r = 0.628$, $p < 0.0005$; MLA: $r = -0.554$, $p < 0.0005$) and week 13 (MC: $r = 0.686$, $p < 0.0005$; MLA: $r = -0.542$, $p < 0.0005$). Also, the change in the Easy index between week one and week 13 was correlated with the changes between week one and week 13 in both MC and MLA (MC: $r = 0.467$, $p = 0.005$; MLA: $r = -0.305$, $p = 0.005$). Change between week one and week 13 in the No idea index was weakly and negatively correlated with the Difficult index ($r = -0.222$, $p = 0.042$).

Student achievement, as evaluated by students' final grade, was correlated with mathematical confidence scores at week 13 ($r = 0.380$, $p<0.0005$) and with the difference in mathematical confidence between week one and 13 ($r = 0.380$, $p=0.001$). None of the other affective attributes or change in those attributes correlated with student achievement. Students' achievement was also positively correlated with the week 13 Easy index ($r = 0.299$, $p = 0.006$) but not by changes in the Easy, Difficult or No idea indices.

Figure 2 shows the relationship between students' final mark dissected with its significant correlates for students with a low tertiary entrance score (OP $\geq$ 11) and those with a high tertiary entrance score (OP $\leq$ 10) [1]. The population intercepts ($p = 0.311$) and slopes ($p = 0.085$) of the regression lines for final mark and mathematical confidence at week 13 (sampled data shown in Figure 2a) can not be considered significantly different for the two groups of students. The sampled slopes depicted in Figures 2b and 2c, are from populations where the slopes are not significantly different ($p = 0.312$ and $p = 0.472$, respectively) but with intercepts that differ significantly ($p < 0.0005$ and $p = 0.041$, respectively).

[1] **:** Queensland OP is not directly convertible to ATAR but, as an approximation, in 2013 OP

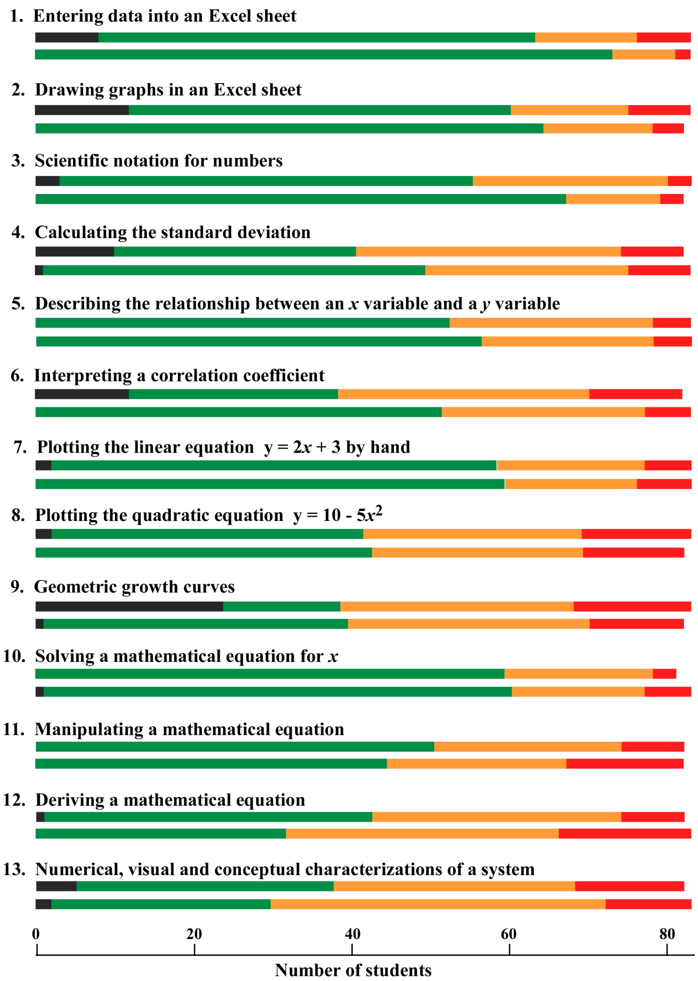
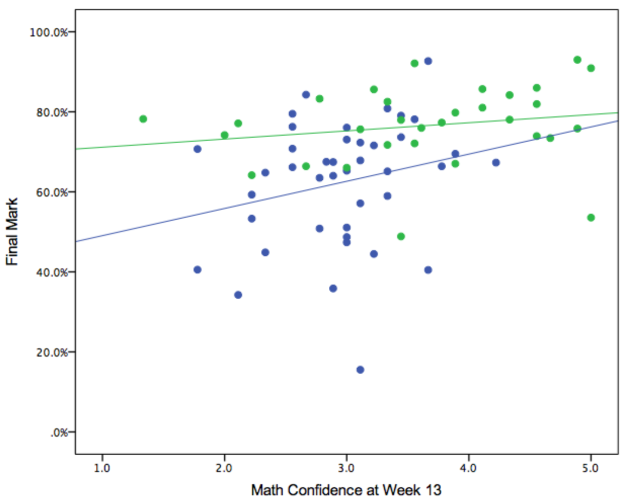
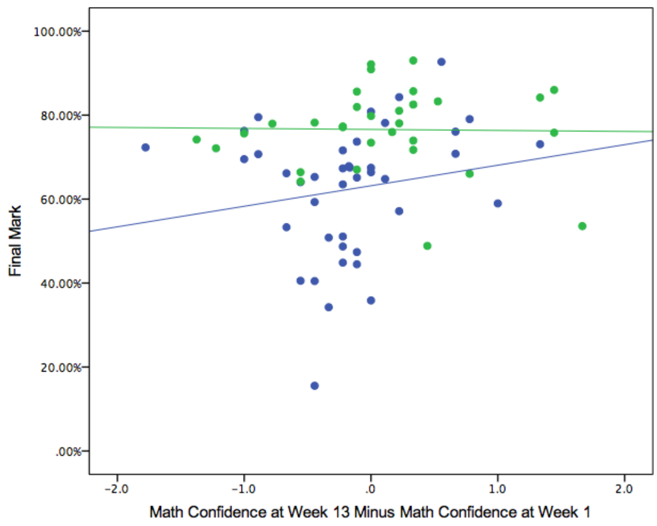


Figure 1: Number of students responding to the 13 topics as Easy (easy + very easy) (green), at times difficult (orange) or Difficult (difficult + very difficult) (red). The number of "No idea/ have not done it before" responses is shown in black. Upper bars start of semester (week 1), lower bars end of semester (week 13). (Note that the number of responses do not always total 84 as the result of missing or ambiguous responses on some returned questionnaires.)

a.



b.



c.

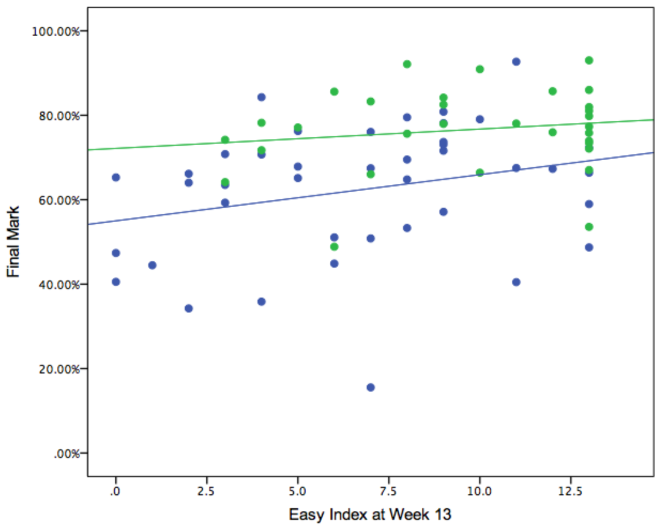


Figure 2: Relationship between final mark and 2a: mathematical confidence at week 13, 2b: change in mathematical confidence, and 2c: Easy index at week 13 for students with a high tertiary entrance score (OP ≤ 10 green circles) and students with a low tertiary entrance score (OP ≥ 11 blue circles).

Discussion

While the need for designing emotionally appropriate learning environments that optimize student engagement is well recognized, attempts to demonstrate successful linkage between the design of learning environments that enhance positive academic emotions and actual achievement are notably absent (Pekrun & Linnenbrink-Garcia, 2012). Our current research investigated if a suite of engagement-focused learning and teaching interventions impacted students' affective attributes and their self-reported ease or difficulty with core competencies for a first year interdisciplinary modelling subject. With regards to aim 1 we found no change between the start and end of semester amongst students in any of the affective attributes. In addressing aim 2 we demonstrated that, reassuringly, students found the set of topics selected from the core competencies of the subject to be easier at the end than at the start of the semester. The appreciable minority of students who had not encountered or recognized some of the topics had dissipated by the end of the semester. Interestingly, fewer students considered topics 11, 12 and 13 easy or very easy at the end than at the start of the semester. These topics (topic 11: manipulating a mathematical equation; topic 12: deriving a mathematical equation; topic 13: numerical, visual and conceptual characterizations of a system) were less specific than the other ten topics. But it is also possible that, at week one, students did not understand the inherent complexities of mastering these topics, but by week 13 they at least understood what was involved and many came to finding these topics very difficult, difficult or at least sometimes difficult. Further work is needed to ascertain the reasons why these three topics ran counter to all the others.

In examining how learning achievement was associated with the measured affective attributes and students self-appraisal of their understanding and skills (aim 3) we found, not unexpectedly, that the higher that students scored on the Easy index the more confident and less anxious they were and their final mark for the subject was higher. Visual inspection (Figure 2 a,b and c) indicates a trend of achievement among the lower entry-level group being more responsive to MC, difference in MC between weeks one and 13, and the score on the Easy index than that of the higher entry-level group. Previous studies have demonstrated that academically weaker students do benefit more from engagement focused interventions than their academically stronger counterparts (Carini, Kuh & Klein, 2006; Gyuris & Castell, 2013). Our data however does not allow similar conclusions because the slopes between achievement and its correlates between the two groups of students, did not reach statistical significance. This limits our findings to the suggestion that the engagement strategies described by Everingham, Gyuris & Sexton (2013) did not advantage or disadvantage one group over the other when their mathematical confidence and self-perceived learning abilities are considered. While the contribution of engagement to student outcomes is not well understood (Carini, Kuh & Klein, 2006) it is necessary that teaching staff deliberately implement and explore the effectiveness of engagement strategies especially for the more vulnerable, academically weaker students. This is especially important at universities with diverse student bodies and that, for various reasons, are unable to offer first year mathematics courses at several levels.

Students' judgment of learning and improvement is a contentious but important area of research (Townsend & Heit, 2011). The metacognitive skill of being able to monitor ones' learning is predictive of students' achievement (Erickson & Heit, 2013). However, despite the importance of self-monitoring ones' knowledge and learning, most people tend to overestimate the ease and efficiency with which they expect to handle various tasks (Stankov & Lee, 2014). This is also the case for students, particularly in tasks involving mathematics. Relative to actual performance, students tend to be much more overconfident in their prediction of their ability to perform mathematical tasks than in their postdiction (self-reported ability after performing a task) for the same task (Erickson & Heit, 2013). However this was reversed in our current study as students' post-completion Easy index increased relative to their pre-completion index. From this we infer that students were able to improve their metacognitive judgment in response to timely and detailed feedback on their performance (one component of the engagement focused interventions, detailed by Everingham, Gyuris & Sexton (2013)), and that students genuinely became more at ease with topics as a result of engaging with the subject. This hypothesis is further supported by the drop in the Easy index from week 1 to week 13 for topics 11, 12 and 13 (see above).

This research was limited by several factors. Firstly, our findings have been based on a single cohort only. It would be interesting to test if the findings from this investigation are consistent across multiple cohorts. Secondly, a wide range of factors affect students' final grade, not just their OP/ATAR and affective attributes. The variability in our data is a further example of the much unexplained variance in students' final marks (Carini, Kuh & Klein, 2006).

Asking students to predict and postdict their score for consecutive class tests coupled with student interviews would have allowed a more controlled estimate of our students metacognitive skills to self judge their ability and knowledge. In future, making available to students prediction and postdiction information together with actual scores and instructor comments would provide them with important feedback; it would also allow teaching staff to more finely tune the learning experiences in the subject as well as assist in guiding students to think more closely about the gaps between what they are expected to know, what they think they know and what they actually know. Such information will be important as university educators strive to create more self-regulated learners while adapting to an increasingly diverse student body.

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