Everingham, Yvette L., Gyuris, Emma, and Connolly, Sean R. (2017) ***Enhancing student engagement to positively impact mathematics anxiety, confidence and achievement for interdisciplinary science subjects.*** **International Journal of Mathematical Education in Science and Technology, 48 (8) pp. 1153-1165.**

https://doi.org/10.1080/0020739X.2017.1305130

Enhancing student engagement to positively impact mathematics anxiety, confidence and learning achievement in the use of mathematics for interdisciplinary science subjects

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Enhancing student engagement to positively impact mathematics anxiety, confidence and learning achievement in the use of mathematics for interdisciplinary science subjects

Abstract

Contemporary science educators must equip their students with the knowledge and practical know-how to connect multiple disciplines like mathematics, computing and the natural sciences to gain a richer and deeper understanding of a scientific problem. However, many biology and earth science students are prejudiced against mathematics due to negative emotions like high mathematical anxiety and low mathematical confidence. Here, we present a theoretical framework that investigates linkages between student engagement, mathematical anxiety, mathematical confidence, student achievement and subject mastery. We implement this framework in a large, first-year interdisciplinary science subject and monitor its impact over several years from 2010 to 2015. The implementation of the framework coincided with an easing of anxiety and enhanced confidence, as well as higher student satisfaction, retention and achievement. The framework offers interdisciplinary science educators greater flexibility and confidence in their approach to designing and delivering subjects that rely on mathematical concepts and practices.

Keywords: student engagement, mathematical anxiety, mathematical confidence, learning achievement, first-year multidisciplinary science,

Introduction

To meet the global challenges of the 21st century, the contemporary scientist must be interdisciplinary. In response to these challenges, more tertiary institutions are introducing their first year science cohorts to interdisciplinary subjects. These subjects build capacity in their students to solve complex problems by simultaneously integrating concepts and processes from multiple disciplines such as mathematics, biology and computing.

It is a much-stated fact that a significant proportion of first year science students are reluctant to participate in the study of mathematics and consequently fail to master the skills necessary for the solution of multi-dimensional challenges of our society ([1] [2]). The consequences of such failure carry personal costs for students, and negatively impact our society as a whole. The high technology, high productivity economy, that developed countries like Australia envision, rely on graduates with well-developed skills in mathematics, the sciences and engineering. Despite well-understood connections between fields of education and indexes of national economic performance, students' engagement with the sciences, mathematics and engineering disciplines is downward trending [1]. Mathematics in particular is seen as the hurdle that many students, for various reasons, are unwilling or unable to surmount ([3]). Yet, mathematics is fundamental to progress in virtually all science-, engineering- and technology-driven studies and consequent employment.

One often cited reason for the failure of many students to develop the required proficiency in mathematics is a phenomenon termed mathematical anxiety [4] [5]). Affected students report intense feelings of tension, fear, apprehension, or, as [6] describes 'sudden death', when they are exposed to mathematical stimuli such as a lecturer working through a mathematics problem or when they attempt to solve a mathematics problem by themselves [7, 8]. Students who experience mathematics anxiety often lack self-belief and confidence in their ability to do mathematics [9, 10, 11] and present low levels of general self-efficacy (Akin, 2011). Lacking in mathematical confidence and/or suffering from high levels of mathematical anxiety can lead to students avoiding mathematics by taking fewer mathematics focused subjects, taking only low level classes, or causing students to disengage from their entire learning process [6, 7, 8, 12]. Reported estimates of the prevalence of mathematics anxiety vary, but it is widely accepted that this phenomenon needs to be taken seriously by researchers, educators and policy makers [5].

Several decades of research focusing on mathematical anxiety investigated socio-economic settings, cultural background, age and gender as potential predictors of mathematical anxiety. A recent review [5] weighed the available information generated by some 60 years of research and concluded that there is no clear association between mathematics anxiety and its hypothesised predictors. This is partially explained by the large degree of confounding between mathematical anxiety and other factors such as trait anxiety (a chronic, generalised tendency to worry excessively), and/or test anxiety (anxiety and worry brought on by examinations and tests or other evaluation of performance), and cultural and social attitudes to mathematics. While the cause(s) and possible treatment of the fear and anxiety associated with mathematics is(are) yet to be fully understood, educators are urgently required to effectively address the problem while awaiting a clear understanding of the psychology of mathematics anxiety and the development of, or consensus on the methods that remove this barrier to learning.

Although agreement on approaches that consistently deliver student success in the tertiary education sector is rare[13], evidence for the effectiveness of student engagement for learning and subject mastery is overwhelming [14]. Researchers also consistently noted that students suffering from mathematics anxiety tend to be less engaged – investing less time, effort and interest in a range of educationally-oriented activities – than non-sufferers[4, 15]. They also tend to perform poorly in assessments relative to non-suffering peers [4, 5]. However, few, if any, studies directly investigated the linkages between strategies to foster engagement and their success in alleviating mathematics anxiety *per se* and its cascade of negative consequences. Clarifying the cause and effect relationship between engagement and mathematics anxiety is made difficult not only because mathematics anxiety is confounded by several other factors (See above) but also because engagement is a highly 'complex and multifaceted meta-construct' [15].

The dominant framework driving engagement strategies in higher education, and in particular the emphasis that universities place on the engagement of first year students, rests on the definition or interpretation of engagement that is described in detail by Kahu [15] as the behavioural perspective. This interpretation focuses on effectiveness of teaching practice, as effected by institutional policy or on the three factors detailed by Zepke [16]: (i) students' investment into their own learning, (ii) teacher and institutional support and (iii) environmental factors external to the institution. While the first two components can be controlled or influenced by the university, the third component cannot; but nonetheless it must be considered in the operationalization of the first two.

In fostering engagement in the first year mathematics classroom, teaching staff must select from a range of generic and also subject specific tools to best suit the subject matter to be learned and mastered that are also appropriate to students' diverse external circumstances. Several researchers have proposed that effective use of technology, such as a computer program in the classroom, can help to improve mathematical confidence and overall mathematics achievement [17, 18]. Other commonly proposed engagement strategies involve bringing real world problems into the classroom as a way to establish relevancy in the role that mathematics can play in the lives of students and the world around them [19]. Taylor and Parsons [20] provide a detailed synthesis of many other engagement strategies. The identification of whether systematic and purposeful application of engagement strategies helps overcoming the mathematics anxiety, that impedes the performance of many students, will be crucial for enabling graduates' critical skill of high level quantitative reasoning.

A recent review of 60 years of research on mathematics anxiety [5] calls *inter alia* for further intervention studies. Here, we report such a study, examining the utility of engagement strategies, that can be implemented by a teaching team in a first year mathematics-focused subject, to alleviate mathematics anxiety and lift student performance. The present study's strengths include its relatively long time series and strong theoretical underpinnings, developed from the pedagogical literature. The purpose of this paper is to evaluate the benefits for learning outcomes and student experience, of an engagement-focused intervention. The intervention is grounded in a theoretical framework, derived from the pedagogical literature that encompasses the issues that resonate from mathematical anxiety, mathematical confidence and student engagement. This evaluation will be conducted for science students enrolled in a compulsory first year interdisciplinary subject at a major regional university in Australia.

The rest of our paper is structured as follows: We first describe the academic and institutional setting of our intervention. We follow by explaining the development and implementation of the theoretical background of the framework that guided our student-centred, engagement-focused intervention. In the methods section we detail the data collection protocols we used to monitor the impact of the intervention. A joint results and discussion section presents quantitative and qualitative data collected and interprets those data. We conclude by highlighting the general applicability and limitations of our framework for engagement-focused enhancement of first year mathematics classes.

Materials and methods

Academic and institutional setting

SC1102 (Modelling Natural Systems) is a compulsory first year science subject for students enrolled in the BSc. The subject interleaves the disciplines of mathematics, natural sciences and computing (Microsoft Excel). SC1102 is packaged into three case studies. The case studies (Sustainable Fisheries – case study 1, Greenhouse Effect – case study 2 and Climate Prediction from Tropical Oceans – case study 3) provide a pathway for students to develop and contextualize the mathematics and computing concepts and skills introduced and used in the subject.

The subject has been offered every year at James Cook University, Australia since 2010, when the curriculum was purposely redesigned to provide their students with a greater and earlier exposure to mathematics and interdisciplinary science. James Cook University engages with a large, under-served population, with a relatively large proportion of its undergraduate students drawn from minority groups and/or disadvantaged socio-economic groups [21]. Across the six years (2010-15) considered in this study, student enrolments in the subject ranged from 178 to 244 students. The overwhelming majority of students (approximately 90%) enrolled in SC1102 indicated a preference to focus their degree in the biological, environmental or earth sciences and only a small proportion followed majors in quantitative disciplines like mathematics or physics.

The first time the subject was offered, students' mathematical confidence was lower at the end of the semester than at the beginning of the 13-week semester, and mathematical anxiety had undesirably increased throughout the semester. Not surprisingly, student retention, academic achievement and overall satisfaction were low. There was a clear and pressing need to modify teaching and learning practices. In response to this challenge, a theoretical framework was developed to guide and provide confidence with approaches to address these problems.

The Intervention

The Theoretical Framework

The theoretical framework that guided new teaching and learning practices is conceptually portrayed in Figure 1. The framework focuses on student engagement for:

i. enhancing student attitudes in the use of technology for learning mathematics,
ii. increasing mathematical confidence, and
iii. attenuating mathematical anxiety.

Moreover, improvement in any one of these three domains is posited to improve overall student satisfaction, and student achievement, and subject mastery.

The benefits that follow higher levels of student engagement are widely applauded in the literature. For example, high levels of student engagement can coincide with positive emotional states, which can then contribute to better retention rates and higher levels of student success [16, 20, 22, 23]. Hence, student engagement is considered a fundamental theme in the conceptual model.

The linkages between the mathematical confidence, software and engagement components of the framework were largely inspired by Pierce and colleagues [17] who hypothesized that effective integration of technologies would increase mathematical confidence in student cohorts and increase student engagement to deliver improved mathematics-based learning outcomes. These workers [17] designed a survey instrument called the 'Mathematics and Technology Attitude Scale', to test their hypothesis. However, they did not directly measure mathematical anxiety. Mathematical anxiety can stimulate a range of negative emotions including increased physiological reactivity, negative cognitions, avoidance behaviour and substandard performance [24, 25, 26, 27]. Until the availability of 9 item 'Abbreviated Math Anxiety Scale'[8], most anxiety scales or surveys had numerous items that made it difficult to measure anxiety concurrently with other attributes. For example, the 'Mathematics Anxiety Rating Scale' [28] has 24 items, and the 'State-Trait Anxiety Inventory' scale has 40 items [29].

Elements of the ‘Mathematics and Technology Attitude Scale’[17] and ‘Abbreviated Math Anxiety Scale’[8] were merged to measure student engagement, mathematical confidence, technology and mathematical anxiety [30]. These authors demonstrated how a series of teaching interventions designed to promote student engagement decreased mathematical anxiety and increased mathematical confidence in the student cohort. However, the authors [30] failed to describe how their interventions were developed from recognised pedagogical themes to provide coherent theoretical underpinnings that encouraged student engagement. Furthermore, given that cohort effects can vary substantially from one year to the next, there is a need to examine if their reported gains could be sustained across multiple cohorts.

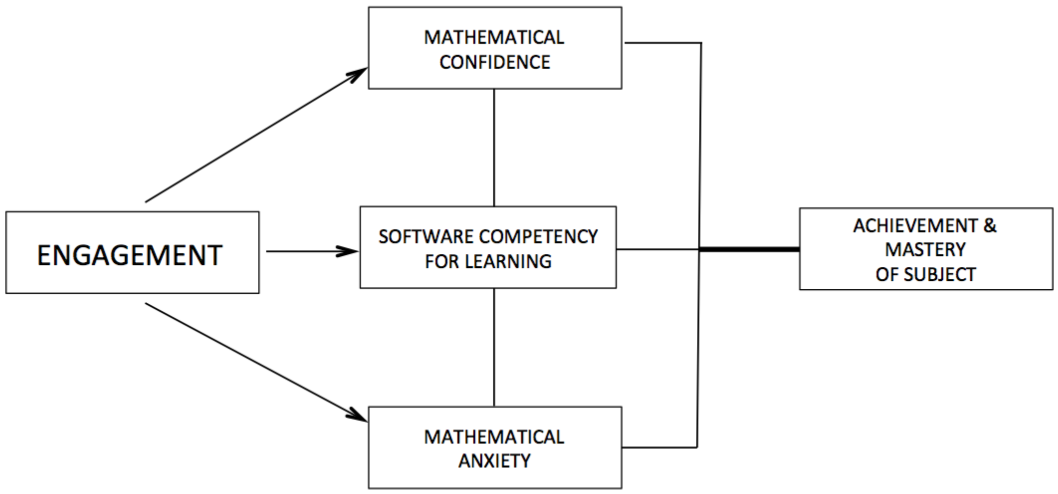

Figure 1: A conceptual model for interdisciplinary science education that is grounded on research in student engagement, mathematical confidence and technology competency in pursuit of improving student learning outcomes and the overall student experience.

The theoretical framework emphasizes the importance of strong student engagement for achievement and mastery of subject material. The definition and understanding of student engagement can vary amongst researchers, but broadly speaking it is a partnership between learners and teachers with the intention to deliver positive impacts on student learning and outcomes [16]. Table 1 lists four common themes that educators have employed to encourage student engagement in learning. These strategies include – (i) creating an environment that promotes interactions between staff and students, (ii) integrating assessments, (iii) establishing subject relevancy and (iv) making effective use of technologies.

Table 1: Common themes that educators have employed to encourage student engagement in learning. Theme 1 is interaction, Theme 2 is assessment, Theme 3 is relevancy and Theme 4 is technology.

Theme	**Description (*References)**
1. Interaction	Students want stronger relationships with their peers, their teachers and they value interacting with experts from outside the classroom. (a, b, c)
2. Assessment	Assessment *for* learning and *of* learning supports the development and integration of assessment items to improve student learning and shape teaching practices. (a, b, d, e)
3. Relevancy	Making the subject matter relevant, gives students an appreciation for how the subject objectives and content relate to real world situations and thus, provides a general sense of purpose to the overall learning experience. (a, b, e)
4. Technology	Effective use of multi-technology learning support tools can have a positive impact on student engagement. When standard

	materials such as textbooks, lecture notes and tutorial tasks can not provide sufficient background for students to learn successfully in a subject, additional teaching support tools, which may be multimedia in nature can be created to complement the course content and make learning more accessible. In the case of mathematics, technology enables mathematical problems to be formulated to solve real world problems and establishes *relevancy* (see Theme 3) in the role that mathematics can play in the lives of students and the world around them. (d, f, g)

* a [31], b [32], c [19], d [20], e [33], f [34], g [17]

Operationalization and implementation of the framework

After the poor learning, engagement, and satisfaction outcomes in SC1102 in 2010, assessment and learning support systems were revised to enhance student engagement. The interventions imposed are described according to the major themes introduced in Table 1.

THEME 1 – Interaction

To adapt to diverse student needs, a range of strategies, focussed on enhancing student and staff interactions, were instigated:

a) Rather than students collecting their assessment pieces from external administrative officers, tutors returned assignments to students at the beginning of tutorials so they could engage in learning conversations, and build student-to-tutor and peer-to-peer relationships.

b) Class tests were returned to students within one week of students taking the test, so rapid feedback could be provided to the students. This created an environment for students to share their answers with each other and to talk about other aspects of the test while it was still fresh in their minds.

c) The subject co-ordinator created a 'team-teaching' environment where tutors could learn and discuss successful techniques from one another, and reflect on the impact of new teaching interventions student learning and how these interventions could be enhanced.

d) At the beginning of a tutorial, tutors would draw on their expertise in interdisciplinary science to recap fundamental material from lectures needed by students to complete the weekly tutorial sheet.

e) A learning advisor provided another avenue for student and staff interactions. The learning advisor assisted students with all aspects of the subject (mathematics, software and science interpretation), including assessment task preparation and utilising to maximum advantage the formative feedback provided by the teaching team. This expertise was possible because the advisor attended lectures and tutorials, allowing her to contextualise the support that she provided to students.

f) Instead of releasing past exam papers and 'practice tests', 'Study Guides' were released that provided pointers to students about what they could do to prepare themselves for class tests and the exam [35].

THEME 2 – Assessment

A variety of assessment strategies were implemented in the subject, each with specific aims and objectives for enhancing student engagement, confidence and success in the material covered:

a) Tutorial sheets were 'signposted' to overview the goals of the tutorial and how the tutorial linked with other tutorial sheets and reinforced terminology presented in lectures.
b) Weekly assignments were devised that provided feedback and guidance to students about where they needed to improve in the subject. The weekly assignments also sparked interactions between students and their classmates and with their teachers (see also Theme 1a)
c) Class tests that followed each case study provided evidence of how well students had grasped key concepts associated with scientific modelling.
d) The co-ordinator judged the cognitive load of each piece of assessment and implemented a consistent style of questioning for the exam, assignments and tests to unify a subject that was delivered by multiple lecturers.
e) The final exam was made optional for students who obtained a credit average or better with the oncourse assessment, but remained compulsory for all other students.

THEME 3 – Relevancy

Before the relevancy of interdisciplinary science and hence the subject could be addressed, teaching staff first needed to increase student familiarity with terms likes 'interdisciplinary science' and 'mathematical modelling'. To this end, a logo [30] was designed to highlight that scientific modelling combines elements of mathematics, computing software and science. The logo was displayed on all class handouts and the subject's textbook. The subject name was also simplified from 'Systems Modelling and Visualisation' to 'Modelling Natural Systems'.

Once the integrated nature of the content was explained, teachers communicated the relevance of the subject material by a number of avenues:

a) Staff reinforced society's need for mathematically literate graduates.
b) An introductory lecture was created that was devoted entirely to the principles, practices and importance of interdisciplinary science and scientific modelling. This lecture explained the different roles that models play in the scientific method (e.g., as idealized constructs in theoretical modelling versus approximate descriptions of regularities in data in statistical modelling), and stressed the need for mathematics to tackle challenges such as resource scarcity, climate change and food security.
c) The case study approach, which introduced students to modelling concepts and techniques, was interleaved with guest lectures. These lectures provided additional example applications for which scientific modelling is essential (e.g. discriminating dolphin sounds, modelling sound waves, estimating past climate from tree rings).
d) Teachers stressed to students that the skills they developed in applying mathematics to describe real world phenomena are transferable to future subjects and a wide range of careers, not just in science.
e) Given the frequent interaction between students and tutors, postgraduate students who use interdisciplinary science and scientific modelling approaches as part of their research, particularly in the biological, earth, and environmental science, were prioritized as tutors.

THEME 4 – Technology

A range of support strategies utilising varied technology-enabled support technologies were integrated into both the formative and summative assessment tasks, with the specific aim of enhancing and improving student learning. These strategies are outlined below:

a) Screencasts that assisted students with the Excel and mathematical components of the course were produced. The screencasts also allowed for consistency in teaching capacity among the multiple tutors.
b) The first time the subject was delivered, Excel was integrated into the course to help students learn mathematics and to establish subject relevancy by providing real life examples. Unfortunately, the first year the subject was offered, there was overwhelming evidence of student frustration to master excel, let alone the mathematical component of the subject. To allow students to become more confident in using Excel, the mathematical part of the subject was delayed so students could become confident in the Excel environment.

Monitoring Affective Attributes and Learning Outcomes

A range of data were collected to measure student attitudes, participation, performance and satisfaction levels. Students' mathematical confidence, mathematical anxiety and attitude towards using technology (Microsoft Excel) competency for learning mathematics was captured in a survey instrument (Table 2) that was administered in 2010, 2011 and 2012 ([30]). Student retention was measured by the proportion of students who submitted at least 80% of their assessment. Student achievement was recorded on a fail, pass, credit, distinction, high distinction rating scale that was determined by student performance across a range of assessment items that included assignments and class tests. Students completed anonymous online surveys to report their overall satisfaction level. The scale was ordinal and ranged from 1 (very low satisfaction) to 5 (very high satisfaction). Qualitative student responses recorded on online anonymous surveys also formed part of the data interrogation procedure. With the exception of data captured by the survey instrument that was recorded for 2010-2012, all other forms of data were monitored for 2010-2015.

Table 2. Items on a survey instrument to measure technology confidence, mathematical confidence and mathematical anxiety. Items are grouped into subscales (TL=technology competency for learning mathematics, MC=mathematical confidence, MLA=mathematics learning anxiety. Items appeared in random order on the survey instrument.

Subscales	**Items**
TL1	I use mathematical software to help me learn mathematics
TL2	I think that I learn more when I use Microsoft Excel in mathematics
TL3	I always find it easy to use *Microsoft Excel* to learn mathematics
TL4	I enjoy using a computer to learn mathematics
TL5	I enjoy using Microsoft Excel for mathematics
TL6	Using Microsoft Excel makes using mathematical tasks more interesting
MC1	I believe that I have a mathematical mind
MC2	I feel confident that I can handle any difficulties in the mathematics that I will study at university
MC3	I feel confident that I can do well in mathematics if I work hard
MC4	I always have the confidence to complete the mathematics in my assignments
MC5	I always find it easy to complete the mathematics in my assignments
MC6	I always find it easy to interpret graphs that explain scientific phenomena
MC7	I always find it easy to interpret formulae that explain scientific

	phenomena
MC8	I always find it easy to draw graphs to explain scientific phenomena
MC9	I always find it easy to write formulae to explain scientific phenomena
MLA1	I feel anxious watching a teacher work an algebraic equation at the front of the class
MLA2	I feel anxious watching a teacher work with a graph at the front of the class
MLA3	I feel anxious when listening to a math lecture
MLA4	I feel anxious when listening to another student explain a math formula
MLA5	I feel anxious when listening to another student explain a math graph
MLA6	I feel anxious when starting a new chapter in a math book
MLA7	I feel anxious when using the tables in the back of a math book.

Results and Discussion

Quantitative assessment of learning outcomes

The Survey instrument was deployed to students at the first and last lectures in 2010, 2011 and 2012. Analysis of these survey results suggests that increased engagement contributed to the increasing trend in mathematical confidence and technology competency for learning mathematics, along with a decreasing trend in mathematical anxiety in the non-math majors (Figure 2).

Following the engagement focussed strategies that were introduced in 2011, overall student satisfaction markedly increased (Item 1, Table 2) and student retention increased from 91% in 2010 to 98% in 2015 (Item 2, Table 2). Post 2010, students demonstrated higher achievement rates (Item 3, Table 1) and the passing rate of students with low tertiary entrance scores was also higher (Item 4, Table 1). This occurred without staff having to reduce the conceptual difficulty of the subject, evidenced by the proportion of students who obtained a High Distinction in the subject, which remained close to 7% in all years.

The guest lecturers varied from year to year, but the main lecture staff were the same from 2010 to 2015. The learning advisor was introduced in 2013 and the tutoring team remained relatively unchanged from 2011 to 2014. A new team of tutors and learning advisor was appointed in 2015. This coincided with a drop in overall student satisfaction back to 2012-13 levels, but remained well above 2010 satisfaction levels. The percentage of students with low tertiary entrance scores who passed also dropped in 2015 to 63%. However, all measures never deteriorated below 2010 scores. Arguably, these outcomes can be credited to the robustness of our theory-driven engagement strategies we employed.

Table 2: Measured impact of student engagement, learning, overall experience. The engagement-focused strategies were introduced in 2011.

Performance criteria	2010	2011	2012t	2013	2014	2015
Overall student satisfaction as determined by the proportion of students who were either satisfied or very satisfied with the subject.	28%	46%	54%	58%	68%	57%
Student retention: Percentage of students that completed at least 80% of the subject's	91%	92%	94%	95%	92%	98%

assessment requirements during the semester.						
Percentage of students in the passing cohort who passed with a credit grade or higher.	58%	71%	74%	67%	74%	72%
Percentage of students with low tertiary entrance scores (OP 11 to 24; ATAR-equivalent 80th to 30th percentile) that passed the subject.	56%	77%	78%	74%	81%	63%

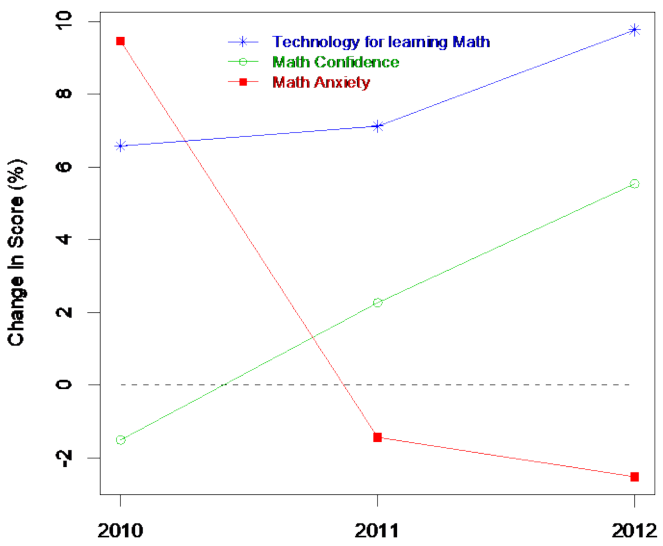

Figure 2: Percent change in mathematical confidence, mathematical anxiety and technology competency for learning mathematics that occurred during semester. In 2010 when the subject first ran, mathematical confidence decreased by 2% and anxiety increased by 10%. When students became more engaged in the subject, as in 2011 and 2012, mathematical confidence increased and anxiety decreased. A new survey was designed for alternate research purposes and administered from 2013, and thus this graph stops at 2012.

Qualitative student feedback

Qualitative feedback from students suggested that placing a greater emphasis on student engagement which followed the themes of (i) interaction, (ii) assessment, (iii) relevancy and (iv) technology, better illustrated to students new concepts associated with interdisciplinary science that they had not encountered previously. Students especially appreciated extra interactions with the learning advisor, introduction by tutors of the tutorial warm-up exercises, and rapid feedback on assessment items (Table 1 – interaction). Not only did the assessment provide opportunity for more interactions, the negotiated assessment in the form of the two-tiered marking scheme motivated students to apply themselves to their studies throughout the semester and offered a sense of security by knowing if they failed the oncourse assessment pieces, they could still obtain a pass if they performed well in the final exam (Table 2 – assessment). The weekly assignments helped students gauge how well they were learning in the subject (Table 1 – assessment). Real case studies and guest lectures demonstrated the relevance of the subject and improved students' ability to solve complex problems (Table 1 – relevance). The screencasts and class study guides provided additional support to students by providing instruction that time did not permit in lectures and tutorials (Table 1 – technology).

Table 3: Qualitative feedback provided by students on teaching interventions imposed to encourage student engagement. The student feedback was provided by students who completed the standard, university-wide, anonymous, online, end-of-semester subject surveys.

Engagement-focused strategies by theme	Examples of students' comments
Theme 1: Interaction Students especially appreciated extra	• 'The learning advisor help sessions were

interactions with the learning advisor, the introduction of the tutorial warm-up exercises by the tutors, and timely feedback provided by tutors.	amazing.' • 'Introducing the warm-up exercises really helped.' • 'The tutors have been great with giving marks back quick and commenting on what I needed to work on.'
Theme 2: Assessment Assessment *for* and *of* learning provided by weekly assignments:	• 'I loved having the assignments each week. They keep your organised and help you learn the content taught in class.' • 'I found the weekly assignments to be very helpful in both practicing and ascertaining how I was going with the topic and the subject as a whole.' • 'Well structured, weekly assessments are a good way to keep students learning the whole semester.'
Negotiated assessment in the form of the two-tiered marking scheme:	• 'The double schemed grading system is also a good idea, making students want to do well during the semester, but allowing them another chance should there be a mishap.' • 'Having 2 different marking schemes has really helped me push to achieve better marks. I have enjoyed having more control over my learning.'
Theme 3: Relevancy Use of real case studies and guest lectures:	• 'The subject is extremely interesting. The fact that we got to study real cases is the best part of it.' • 'The subject was presented in a way that did engage it's listeners, and gave a broad understanding of an otherwise inaccessible form of thinking.'

	• 'The variety of case studies is good and relevant to our future careers.' • 'Although this subject irritated me at first, I understand its relevance and I think it has improved my ability to understand and solve complex problems.' • 'Guest lecturers put what we were learning into a context of real-life research'.
Theme 4: Technology Screencasts and class study guides:	• 'Screencasts were a big help in understanding tutorial questions.' • 'Screencasts - its how I learn!' • 'The class study guides were excellent.'

Conclusions

Mathematics plays an important role in contributing solutions to large-scale socio-scientific issues such as food security, renewable energy and environmental sustainability. Hence, there is a clear and pressing need to advance our knowledge on pedagogical practices that help educators effectively deliver interdisciplinary science subjects, which have a substantial mathematical component, to students whose major lies outside the mathematical sciences.

This paper proposed a framework for enhancing student engagement as a means to overcome mathematical anxieties and low levels of mathematical confidence, and to facilitate the mastering of concepts and practices in interdisciplinary science. Implementing the theoretical framework enabled the teaching team to employ an adaptive approach for the continuous improvement of the subject that remained faithful to the original purpose and vision of the subject. We found that a focus on strategies for engagement indirectly enhances subject mastery and achievement and, most notably, this effect was mediated via reduced mathematical anxiety, plus enhanced competency with computing software and a concurrent increase in confidence with mathematics.

The framework does have limitations. The framework has been targeted towards science education, but the approach can easily be extended to other interdisciplinary areas that require mathematical literacy, such as economics, health, and social sciences. Also, as a matter of simplicity, the framework does not consider feedbacks between student engagement, mathematical confidence, mathematical anxiety, software competency and achievement, although they clearly exist. Despite these limitations, our framework does recognise critical factors that must be carefully considered by educators when designing and delivering subjects that rely on mathematical concepts and procedures.

Declines in mathematics enrolments at high school are worldwide and extend beyond cultural and national borders. If we are to train professional scientists to contribute to large-scale socio-scientific issues such as food security, renewable energy and environmental sustainability, then educators must develop strategies that are underpinned by theories that address the obstacles imposed by the global declines in numeracy skills. Given these challenges, it is imperative that tertiary educators share their pedagogical philosophies about teaching interdisciplinary science to deliver better student learning outcomes.

Acknowledgements

The authors would like to acknowledge the efforts of all SC1102 teaching staff and SC1102 students who have provided feedback about the subject. Funding provided by

James Cook University and Australia's Office for Learning and Teaching for helping to improve the subject is gratefully acknowledged. The authors would also like to thank Daniel Zamykal, Angela Hill, Renae Acton, Nick Emtage and Sally Kift for their assistance with this manuscript. Research was conducted as permitted by James Cook University's Human Research Ethics approvals H3756 and H5209.

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