For innovative team-based approaches to enhancing first-year students' engagement, confidence and learning achievement in the use of mathematics - the common language for the natural sciences

CONTEXT

In Australia, there has been a catastrophic decline in the proportion of students who study mathematics at university (Rice et al., 2009; West, 2012) and an increase in the proportion of students entering universities with low numerical literacy. This problem is particularly acute at universities in regional Australia, where there is often a shortage of mathematics expertise in secondary schools. At the same time, many science disciplines are increasingly making use of sophisticated mathematical and computational methods, including the biological, earth, and environmental sciences. Consequently, among first year science students there is a critical need to improve numeracy skills, and reduce anxiety about mathematics. We developed a new **compulsory** first year interdisciplinary mathematical modelling subject called "Modelling Natural Systems" for the Science Faculty at James Cook University as the vehicle to achieve these goals. This subject was first delivered in 2010 to 175 students and most recently delivered in 2013 to 229 students. Students enter the subject from very diverse educational backgrounds – in 2010, students with a tertiary entrance rank between the ATAR score of 50- 80 constituted less than one-third the class size. This fraction has risen each year and was almost half the class in 2013. *"Programs like this, which demonstrate how to tackle these problems effectively, are rare and need to be recognised and showcased"* (Professor John Rice, External referee).

Our challenge was to design and deliver a subject that motivated students by emphasizing the broad relevance of mathematics and computing throughout the sciences, whilst developing mathematical and computer literacy for students with a very broad range of university entry scores and levels of anxiety about mathematics. To meet this challenge, we created a multi-disciplinary team skilled in learning, teaching and education research, as well as in applying mathematics in the biological, earth and environmental sciences. We also established a subject consultative committee to promote continuous improvement. This was essential to (i) develop teaching and learning strategies that engage with students traditionally under-represented in higher education; (ii) showcase to students the contribution of mathematics to disciplines in which they plan to major; (iii) navigate institutional barriers and overcome logistical challenges; and (iv) gain the support of all academic units in the Science Faculty. *"This subject has been VERY thoroughly thought out. A huge thanks is due to Yvette and her brilliant team"* (Student evaluation, 2013).

Knowing that engagement is pivotal to student achievement (Kuh, 2001) and the impacts that mathematical confidence and anxiety have on achievement (Pierce et al. 2007, Hopko et al. 2003) we created a theoretical framework (Figure 1) to guide subject design and delivery. We hypothesised that strong student engagement would promote students' competency in the use of software used for learning mathematics, increase mathematical confidence, and attenuate mathematical anxiety. Improvement in any one or more of these three domains was expected to improve learning outcomes. Thus, our subject design consistently focused on the enhancement of student engagement, leveraged by innovative approaches to feedback, assessment and learning support.

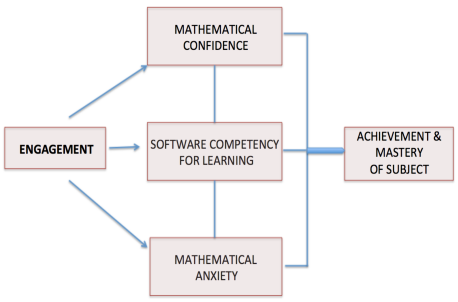

*Figure 1: A conceptual model of our team's framework for the **adaptive development** of the subject*

ASSESSMENT CRITERIA # 3: INNOVATIVE APPROACHES TO ASSESSMENT, FEEDBACK AND LEARNING SUPPORT THAT FOSTER INDEPENDENT LEARNING

Our theoretical framework has allowed an **adaptive approach** for the **continuous improvement** of the subject that remained faithful to our original purpose and vision. The framework guided our team in the development and acquisition of summative, formative and qualitative feedback to and from the students. This novel feedback strategy included:

a) **A new and unique survey instrument** was developed. We consulted instruments published in the educational literature that surrounded student perceptions of (i) engagement (ii) software technologies for learning mathematics (iii) mathematical confidence and (iv) anxiety. Unfortunately, very few

authors have considered these matters simultaneously. To overcome this shortcoming, we constructed a new survey instrument that measured these elements concurrently (Everingham et al., 2013).

b) **Summative student feedback,** including qualitative feedback from the student surveys and focus group interviews, was captured together with students' tests and exam results.

c) **Formative feedback** included student performances on weekly assignments.

Triangulating among these feedback strategies and interpreting the feedback through the lens of the theoretical framework allowed us to identify areas that would continuously improve the subject.

Figure 1 emphasises the importance of strong student engagement for achievement and mastery of subject material. Hence, assessment and learning support systems were designed strategically to **enhance student engagement**. *"The subject was presented in a way that did engage its listeners, and gave a broad understanding of an otherwise inaccessible form of thinking"* (Student evaluation, 2013). Because student engagement is a multi-dimensional concept, several actions were needed to maximise the likelihood of improved engagement. These actions, listed below, can be categorized according to themes described in Windham (2005), Willms et al. (2009) and more recently Taylor & Parsons (2011).

THEME 1 – Enabling intensive and varied student and staff interactions

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

- **Providing timely, worthwhile feedback to students on their learning:** Tutors' expertise in the subject matter enhanced the feedback provided to students. Tutors returned assignments to students in tutorials so they could engage in learning conversations, and build student-to-tutor and peer-to-peer relationships, marked within one business day. *"The tutors have been great with giving marks back quick and commenting on what I needed to work on"* (Student evaluation, 2012).
- **Engaging and empowering tutors:** The subject co-ordinator created an environment where tutors could learn successful techniques from one another, report to senior staff about the impacts of teaching interventions on student learning, and help to identify how these strategies could be improved.
- **Tutorial "warm-ups":** At the beginning of a tutorial, tutors would draw on their expertise to recap fundamental material from lectures needed by students to complete the weekly tutorial sheet. *"Introducing the warm-up exercises really helped"* (Student evaluation, 2013)*; "The tutorial and warm-up exercises were also great"* (Student evaluation, 2013).
- **Learning advisor:** In 2013, to assist students with the conceptual matter in the subject, a learning advisor contributed her professional expertise to assist 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. *"The learning advisor help sessions were amazing"* (Student evaluation, 2013).

THEME 2 – Assessment of learning and for learning

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

- **Adapting assessment methods to diverse student needs and learning styles:** Weekly assignments provided guidance to students about where they needed to improve in the subject. *"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* (Student evaluation, 2011). Class tests provided evidence of how well students had grasped key concepts associated with scientific modelling. 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. *"Having 2 different marking schemes has really helped me push to achieve better marks. I have enjoyed having more control over my learning" (Student evaluation, 2013). "An ingenious feature of the new assessment regime involved students effectively choosing how they were to be assessed. Allowing students to 'have a say' in how they are assessed, empowers students which usually has the effect of increasing engagement"* (A/Professor Carmel Coady, External reviewer).
- **Contributing professional expertise to enhance assessment and/or feedback:** The co-ordinator judged the cognitive load based on the interdisciplinary complexity of the task and implemented a consistent

style of questioning for the exam, assignments and tests to unify a subject that was delivered by multiple lecturers.

THEME 3 – Relevant and authentic assessment tasks

Taking the diverse needs of the student cohort into account, the need to develop relevant and contextualised learning experiences became apparent, as did the need to clearly communicate the integrated nature of disciplinary content. As such, a logo was designed to highlight that scientific modelling rolls into one the elements of mathematics, technology 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, we communicated the relevance of the subject material across two dimensions. Firstly, we highlighted the need for mathematically literate science graduates. An introductory lecture was devoted entirely to the principles, practices and importance of scientific modelling which stressed that mathematics was needed to tackle challenges such as resource scarcity, climate change and food security. Subsequently, a case study approach to introducing modelling concepts and techniques, coupled with a series of guest lectures, provided contextual relevance of the importance of scientific modelling. *"The subject is extremely interesting. The fact that we got to study real cases is the best part of it"* (Student evaluation, 2013). Secondly, we stressed to students that the skills they develop in this subject are transferable to future subjects and a wide range of careers. *"The variety of case studies is good and relevant to our future careers (Student evaluation, 2012). "I just wanted to email and say a huge thank you … I found out when I opened the practical for my second year Geology subject that we would be interpreting data using excel data plots and hypothesizing on what we found. I'm really glad that because of the study I did I was able to accomplish the work put before me and enjoy it also"* (Unsolicited student email, 2013). Postgraduate students who use mathematical models for research, particularly in the biological, earth, and environmental sciences, were prioritized as tutors, because they were best-placed to reinforce to students the subject's relevance throughout the sciences. *"The tutors deserve to be highly commended. They were amazing and motivated us students to do well"* (Student evaluation, 2011).

THEME 4 – Varied technology enabled support materials

Several support strategies 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:

- **Staggered integration of technology and mathematics:** Using software like Excel to learn mathematics can be a double-edged sword. It can easily generate student frustration and have a negative impact on the intended goal. To allow students to become confident in using Excel the mathematical part of the subject was delayed so students could become confident in the Excel environment. A series of cartoons was designed to forewarn students that when a new software program is learnt, one typically traverses three emotions – *Fear, Frustration* and *Familiarity*. The "Familiarity" cartoon has been displayed to the right.

- **Screencasts:** Screencasts that assisted students with the Excel and mathematical components of the course were produced. The screencasts allowed for consistency in teaching capacity among the tutors. *"Screencasts were a big help in understanding tutorial questions"*(Student evaluation, 2013).
- **Class Study Guides:** Detailed study guides for class tests and the exam were provided to students. *"The class study guides were excellent"* (Student evaluation, 2012).

HAVE THE CHANGES INFLUENCED STUDENT LEARNING, STUDENT ENGAGEMENT OR THE OVERALL STUDENT EXPERIENCE?

In addition to doubling student satisfaction levels (Student evaluations, 2010-2013), the series of actions to increase engagement corresponded with an increasing trend in mathematical confidence and software competency for learning mathematics along with a decreasing trend in mathematical anxiety in the non-math majors (Figure 2). The number of students who disengaged from the subject after the HECS Census date nearly halved (Item 1, Table 1). Students demonstrated higher achievement rates (Item 2, Table 1)

and the passing rate of students with low tertiary entrance scores increased without reducing the conceptual difficulty: for instance, the percentage of High Distinctions was the same (7%) in 2013 as it was in 2010 (Item 3, Table 1).

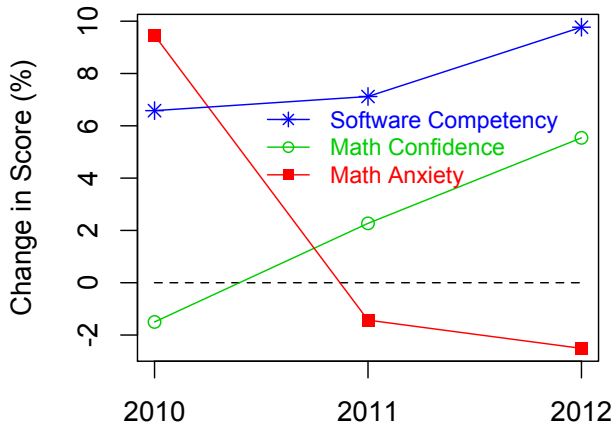

Figure 2: Percent change in mathematical confidence, mathematical anxiety and software competency for learning mathematics that occurred during semester. In 2010 when the subject first ran, mathematical confidence decreased by 2% and anxiety increased by 10%. When students became more engaged in the subject, as in 2011 and 2012, mathematical confidence increased and anxiety decreased. The survey instrument was redesigned for 2013, and thus is not plotted here.

Table 1: Measured impact of student engagement, learning and overall experience.

Item	2010	2011	2012	2013
1. Students that disengaged after the HECS Census date	10.7%	9.0%	7.2%	6.8%
2. Percentage of the passing cohort who obtained a Credit grade or better	58%	71%	74%	67%
3. Pass rate of students with a tertiary entrance rank between the ATAR score of 50 – 80	56%	77%	78%	76%

RECOGNITION FROM FELLOW STAFF, THE INSTITUTION AND/OR THE BROADER COMMUNITY

Our team received a *2014 JCU Citation for Outstanding Contributions to Student Learning* providing evidence of institutional recognition of the innovative nature of our approach. In addition, the team received the prestigious 2014 overall best JCU Citation award. The team has further produced **four publications**: two international peer reviewed journal articles (Everingham et al., 2013; Gyuris et al., 2012), and, at the premier Australian Conference on Science and Mathematics Education, a peer reviewed conference paper (Gyuris & Everingham, 2011) and a poster on the same theme (Everingham & Gyuris, 2012). Our team's approach was also presented in a 3 minute news item on **ABC radio** (Patrick Hessian's ABC drive time session, Sep 2013) and **externally reviewed** by Associate **Professor Carmel Coady** (Director of Academic Programs, Mathematics and Statistics, University of Western Sydney) Coady and Rice both noted the significant challenges faced by our team of delivering a mathematics based unit in a non-mathematics based degree to a high proportion of students and low tertiary entrance scores. Higher education in the sciences must respond to two powerful and countervailing forces that are exacerbated by the "massification agenda". Our team has fostered sustained improvement in first year science students' engagement, confidence, and learning achievement in the use of mathematics. This was achieved through innovative approaches to assessment and instruction that emphasised timely, worthwhile feedback, relevance and relationship building. In the words of our external assessor, our team *"has succeeded in providing non-mathematics majors with a compulsory mathematics-based subject that utilises the tenets of the authentic science curriculum. Assessment, feedback and learning support are critical elements of the student learning experience. The holistic approach taken by the team, where achieving the learning outcomes has been the driver of the learning design incorporating these elements, has resulted in a very positive learning experience for students"* (A/Professor Carmel Coady, External reviewer).

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