Maths Anxiety in a First Year Introductory Quantitative Skills Subject at a Regional Australian University – Establishing a Baseline

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Abstract

Mathematics anxiety is a well recognized and for many students a performance inhibiting impediment. As part of a larger study aimed to guide interventions to improve quantitative skills of science students we investigated students' entry-level maths anxiety, explored its effect on their performance and observed how anxiety and different assessment schedules interacted to affect performance in a first year compulsory quantitative skills subject. Students' preferred discipline significantly correlated with anxiety, and students' performance in invigilated assessment items correlated with mathematics evaluation anxiety, although the pattern of correlation was found to be different in the two years of the study. The many confounding variables that impact on student anxiety and performance make it difficult to identify the extent to which scores achieved on the different facets of Abbreviated Mathematics Anxiety Scale can affect a students' final score in a compulsory first year quantitative skills subject. Nevertheless, a baseline understanding has been established which, at the very least, raises an awareness of potential issues associated with maths anxiety that can in turn be used to guide any subsequent interventions.

Introduction

In Australia, as in other OECD countries, there has been a well-recognized, long-term and precipitous decline in university enrolments in the Science-Technology-Engineering-Mathematics (STEM) disciplines (Organisation for Economic Co-operation and Development Global Science Forum, 2006; House of Representatives Standing Committee on Education and Training, 2009). Concurrently, students choosing to enroll in science-based degree programs are increasingly poorly prepared in the enabling sciences, including mathematics and statistics (Brown, 2009; House of Representatives Standing Committee on Education and Training, 2009). Many education researchers and teaching academics, lamenting these trends and their multiple consequences, have noted that a high proportion of students display a pronounced fear or anxiety of mathematics and/or statistics (Baloglu & Kocak, 2006). Students' subject choices reflect their fears as they show an avoidance of subjects that rely on quantitative skills or theory (Ashcraft & Krause, 2007; Ashcraft & Moore, 2009). Yet, at some stage of a science-based degree program, even in the so-called "soft sciences" such as ecology or environmental science, students need to master mathematical and statistical skills. It is at this point that the performance of many otherwise capable students suffer, potentially limiting their academic progression and career prospects (Brown, 2009; Hembree, 1990). Given the high demand and low supply of graduates displaying competence in quantitative skill based subjects, it is important that we put systems in place to reverse this situation.

To address the problem of poor engagement with and fear of the enabling sciences, including quantitative skills, the Faculty of Science and Engineering of James Cook University (JCU) undertook, in 2009, a major restructure of its first year of the Bachelor of Science (BSc) degree. This was achieved with funding from the Department of Education, Employment and Workplace Relations through its Diversity and Structural Adjustment Fund. This restructure included two significant components that addressed the lack in students' quantitative skills. Firstly, the faculty improved its communication to enrolling students about knowledge needed for entry by first year science students. The ambiguous and confusing sets of requirements, especially with regards to mathematics, for admittance into the different disciplinary majors of the BSc were replaced with uniform and clearly articulated prerequisites that now include senior Mathematics B (in Queensland, Australia, it is the recommended precursor to tertiary studies in the areas of science, engineering, medicine, mining, information technology, mathematics, finance, and business and economics). Secondly, the faculty developed a new subject, SC1102: Modelling Natural Systems, as a core component of the first year of the BSc. SC1102 was developed as an inter-disciplinary, case-study based science subject designed to build capacity in students' ability to work both within and across multiple disciplines similar to the model described by Matthews, Adams and Goos (2009). Specifically, the subject demonstrated how knowledge of natural scientific systems can be enhanced through the effective integration of mathematics and computing (e.g. predicting the risk of cyclone occurrence). This was done with the view to heighten student awareness of the advantages of being quantitatively literate as did Matthews, Adams, and Goos (2010).

The long history of research on maths anxiety has been previously summarized by Ashcraft and Moore (2009) and Zeidner and Matthews (2011). Despite the voluminous literature on the topic over the last thirty years, contradictions and uncertainties still exist about which students are most likely to exhibit high levels of maths anxiety as against anxiety as a personality trait or generalized high-stakes test or evaluation anxiety (Hembree, 1990; Mellamby & Zimdars, 2010). Gender and age often, but not always, are shown to be significant predictors of maths anxiety (Andile, 2009; Baloglu, 2002; Baloglu & Kocak, 2006; Hembree, 1990; Sirmaci, 2007) and more recently the level of preparedness or previous experience of mathematics and statistics emerged as reliable predictors of anxiety (Ashcraft & Moore, 2009; Baloglu, 2002; Baloglu & Kocak, 2006).

Furthermore, no unifying statements can be easily made about the impact of maths anxiety on student achievement (Kyttälä & Björn, 2010). High levels of maths anxiety often result in impaired performance (Ashcraft & Moore, 2009; Hembree, 1990; Payne & Israel, 2010). However in a study spanning 41 countries and boasting a sample size of quarter million students, the impact of anxiety on performance varied significantly amongst different populations (Lee, 2009). Some populations scoring high on the maths anxiety scale also performed well on the maths scores of the Program of International Student Assessment (PISA). Many studies highlight the negative correlation between maths anxiety and maths performance (Ashcraft & Moore, 2009; Hembree, 1990; Payne & Israel, 2010). Yet others detect an opposite effect: some students, often females, scoring highly on various anxiety scales perform better than students with low anxiety levels (Mellamby & Zimdars, 2010).

Unlike most other studies that presumed a linear relationship between academic performance and anxiety Keeley, Zyac, and Correia, (2008), with strong theoretical reasoning, hypothesized and subsequently demonstrated a curvilinear relationship between performance and statistics anxiety amongst undergraduate students.

In the present study we sought to:

1) identify the variables that may affect maths anxiety of our students;
2) measure pre-existing maths anxiety levels of students entering the BSc;
3) explore the relationship between this pre-existing maths anxiety and performance in SC1102;
4) observe how anxiety and different assessment schedules interact to affect performance.
5) extend the findings of Gyuris & Everingham (2011) with the inclusion of a second year of data collection;

Materials and methods

Questionnaire development

Our instrument for measuring the level of first year science students' mathematics anxiety also included components investigating students' mathematical confidence, affective engagement, behavioural engagement attitude to technology associated with the study of mathematics. The anxiety scale itself, pertinent to this current research, consisted of the Abbreviated Maths Anxiety Scale (AMAS) of Hopko, Mahadevan, Bare and Hunt (2003) with some minor modifications, plus two additional items in consideration of our student populations and the context of the subject, SC1102, in which the students were enrolled (Table 1). We chose the anxiety scale of Hopko et al., (2003) because its brevity was considered a significant advantage and it compares well with other widely used maths anxiety rating scales (Ashcraft & Moore, 2009). Students responded to items on our modified AMAS using a 5-point Likert scale ranging from 1 (low anxiety) to 5 (high anxiety), with the total score representing the mean response of the eleven items.

Whilst it is common practice to use both affirmatively and negatively worded items, all our questions were affirmatively worded because we wished to avoid the frustration and confusion that may be caused by oscillating between affirmatively and negatively worded items. Since the AMAS was interspersed with items from other scales (not related to anxiety and thus not shown here), many of which pertained to the enjoyment or positive actions or emotions about mathematics, we contend that some of the issues of respondent fatigue and acquiescence bias were thus alleviated (Saris, Revilla & Shaeffer, 2010). Also, since the questionnaire was to be administered at least twice to the same student we did not want the questionnaire to be a catalyst for negative thinking (Pierce, Stacey & Barkatsas, 2007).

For each participant we also collected demographic information about gender, first language learnt, their domestic or international status, number of years elapsed since leaving school and the science discipline that most interested them. Students' final grades, including any withdrawals from the subject were extracted from the university records. Mid-term test results were available from the class records. All categorical variables had two outcomes e.g. gender (male, female), except the "time since students left school", which had 3 categories (less than one year; one to five years (inclusive); more than 5 years)."

Table 1: Comparison of the AMAS as developed by (Hopko et al., 2003) and the modified AMAS administered in the current study. Items unique to our study are asterisked. Instructions given to respondents are also shown. Items relating to the maths learning anxiety (MLA) and maths evaluation anxiety (MEA) subscales are identified in the far right column. One item (#) was excluded from both subscales (See text for discussion).

AMAS (Hopko et al. 2003) Please rate each item in terms of how anxious you would feel during the event specified. Use the following scale and record your answer in the space to the left of the item: Scale: 1 = Low Anxiety through to 5 = High Anxiety	**Modified AMAS** How much do you agree with these statements about your study? (Circle the most appropriate answer - place a line through the question if you are unable to answer) Scale: 1 = Strongly disagree through to 5 = Strongly agree	
thinking about an upcoming maths test 1 day before	I feel anxious thinking about a maths test coming up the next day	MEA
watching a teacher work an algebraic equation at the front of the class	I feel anxious watching a teacher work an algebraic equation at the front of the class	MLA
	I feel anxious watching a teacher work with a graph at the front of the class *	MLA
taking an examination in a maths course	I feel anxious when taking an examination in a maths course	MEA
being given a homework assignment of many difficult problems that is due the next day	I feel anxious about a maths assignment that is due in the next class	MEA
listening to a lecture in maths class	I feel anxious when listening to a maths lecture	MLA
listening to another student explain a maths formula	I feel anxious when listening to another student explain a maths formula	MLA
	I feel anxious when listening to another student explain a maths graph *	MLA
being given a pop-quiz in maths class	I feel anxious when being given a not-for-credit “pop” quiz in maths class	#
starting a new chapter in maths class	I feel anxious when starting a new chapter in a maths book	MLA
having to use tables in the back of a maths book	I feel anxious when using the tables in the back of a maths book.	MLA

Assessment schedules

In both survey years assessment consisted of on-course assessment (both invigilated and non-invigilated items) and an invigilated end of year examination. However there were significant differences in the schedules between 2010 and 2011: In 2010 each student completed one invigilated class test (weighted at 20%) and a single final examination (weighted at 50% and consisting of theory and practical components) as well as a number non-invigilated assignments (total of 30%). The final grade for the subject was the weighted average over all assessment items and the passing score was a minimum of 50%.

In response to student feedback the assessment schedule was revised in 2011 as follows: During the 13 week semester students completed three invigilated class test and non-invigilated assignments. At the end of the semester an interim total score was calculated for each student with each class test contributing 30% and the assignments the remaining 10% towards the interim final total score. Those students achieving lower than 65% for their interim score were required to sit a final examination. The final examination was optional for students achieving a weighted interim average of 65% or higher. For students taking the examination a second total score was then calculated as the weighted average of the class tests (this time taken at a weight of 10% each), the examination (60%) and the non-invigilated assignments (10%). The passing score was again defined as a minimum of 50%, and for students taking the examination as an option the higher of the two total scores defined the final grade for the subject.

Statistical Analysis Methods

A factor analysis with a rotated varimax solution was used to investigate the results of the modified AMAS questionnaire. Cronbach's alpha was used to measure the internal consistency of items. Kruskal Wallis tests of significance were employed to investigate the affect of categorical variables on quantitative responses. Specifically, we performed the two tailed test which has the alternative hypothesis of "at least one of the populations tends to yield larger observations than at least one of the other populations", as described by Conover (1999, pp 290). We note that the Kruskal Wallis test is indeed equivalent to the Mann-Whitney test and thus can be applied to the situation with two populations (Conover, 1999, pp 296). We used the Bonferroni error correction to account for the number of tests conducted. To examine the relationship between anxiety scores and students' performance we used stepwise forward regression models that included both linear and quadratic terms for continuous variables. Dummy variables were created for categorical variables. All first order interactions between dummy variables and linear continuous variables were considered for significance. Exploratory data analysis was conducted by inspection of boxplots and scatterplots. The subscript "KW" denotes the p-value associated with a Kruskal Wallis test, and a subscript of "R^2" denotes a test of the significance for the population r-squared value (R^2). Since the number of variables varied in the models, we report the adjusted R^2 (R^2adj) to facilitate comparison of the regression models of varying complexities. Statistical analyses were performed using SPSS version 17.

Results

Our student cohort

Response rate to the questionnaire was 70% in 2010 and 69% in 2011. Demographic variables of the two student cohorts are provided in Table 2. The two cohorts were remarkably similar in composition.

When students were asked to identify “which area of science interests you the most” (preferred discipline in Table 2), the biological and environmental sciences were chosen most frequently. Some students however chose two disciplinary areas and so not to discard valuable information we split students into two groups: those with a preference that included at least one of maths and/or physics (=the “maths-physical sciences group”) and those whose preferences included neither (=“biological/earth/environmental sciences group”). In both years the maths-physical sciences group was biased towards males. (Numbers in table 2 are not consistent as not all students identified themselves for each attribute.)

Table 2: Demographic composition of student respondents

Proportion of respondents	2010 cohort % (n)	2011 cohort % (n)
Male	38.1 (53)	42.9 (76)
Domestic student	84.8 (117)	87.6 (155)
School leaver	51.4 (71)	46.9 (83)
Left school <5 years ago	35.6 (49)	36.2 (64)
Mature aged	13.0 (18)	16.9 (30)
Non English speaking background	12.4(17)	15.3 (27)
Preferred discipline includes maths/physics	11.6 (16)	12.0 (21)

Validation of the survey instrument

The eleven-item modified AMAS had high internal consistency with Cronbach’s alpha=0.910, conforming very closely to the alpha of 0.90 reported by Hopko et al. (2003) for the original nine-item AMAS. Factor analysis of the 11-item modified AMAS identified two factors equivalent to anxiety associated with maths evaluation (MEA) and anxiety associated with maths learning (MLA) as also described by Hopko et al. (2003). For computation of the factor scores we removed item nine of the modified AMAS (Table 1) as this item loaded equally on both factors – MEA and MLA. Cronbach’s alpha for the two subscales was 0.826 for MEA and 0.885 for MLA.

Patterns of anxiety among our students

We examined how each of the five demographic variables (gender, domestic/international status, years since leaving school, disciplinary interest and language learnt from birth) affected anxiety scores of the 11-item modified AMAS and each of the two subscales, MEA and MLA.

Within both cohorts overall anxiety was significantly different between the maths-physical sciences group and the biological/earth/environmental sciences group (modified AMAS, p_{KW}=0.001 for the 2010 cohort and p_{KW}=0.004 for the 2011 cohort) with the boxplots of the maths-physical sciences group being lower than that of the biological/earth/environmental sciences group (Figure 1). A similar result occurred for MEA (p_{KW}= 0.005) for the 2010 cohort. All other differences between the two disciplinary groups were considered non-significant after the Bonferroni correction. The observed differences between these two groups of students were expected as high mathematics self-efficacy (i.e. the belief of being good at maths) is a driving force behind students selecting mathematics and physics based majors (Betz & Hackett, 1983; Hackett & Betz, 1989; Lindstrom and Sharma, 2011). The result concurs with studies incorporating a wider base of majors such as the study of Durrani and Tariq (2009) who observed that those undergraduates in the UK that considered themselves more numerically competent also expressed lower levels of anxiety.

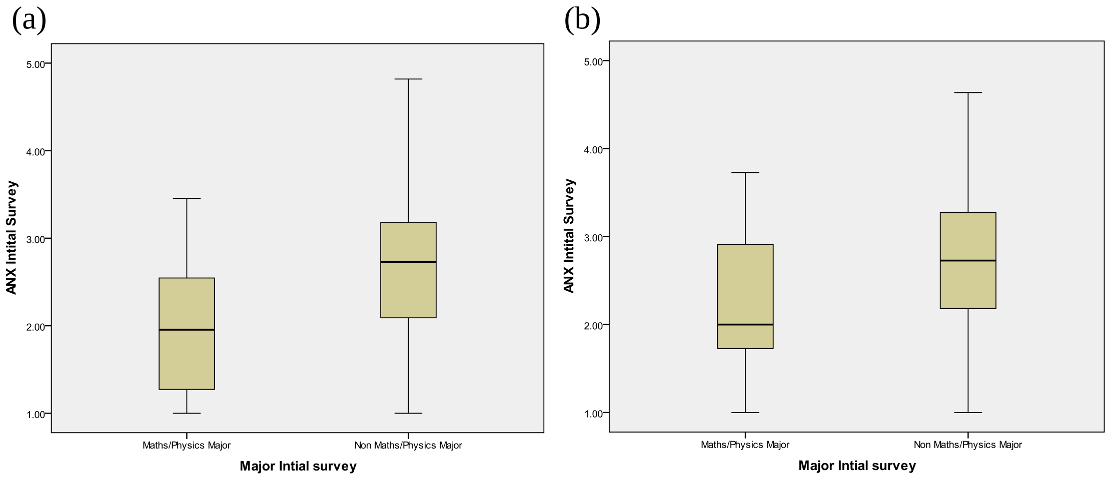

Figure 1: Boxplots of anxiety scores for 2010 (a) and 2011(b) cohorts of maths-physical sciences group (left) and biological/earth/environmental sciences group (right).

Gender affected the overall anxiety scale only in 2010 (modified AMAS, pkw=0.008) with the boxplots (Figure 2) displaying females' anxiety levels to be shifted higher than that of males. This finding supports other studies, such as Hembree's (1990) meta-analysis of some 151 studies and numerous later studies (Hopko et al. 2003; Hyde, Fennema, & Lamon, 1990; Kyttälä, & Björn, 2010) that identified significantly higher anxiety in female students than in male students. However other studies have failed to demonstrate a gender difference in maths anxiety (Andile, 2009; Baloglu, 2002; Haynes, Mullins, & Stein, 2004; Sirmaci, 2007). The literature provides no clarity as to the reasons for any of the observed gender differences in maths anxiety.

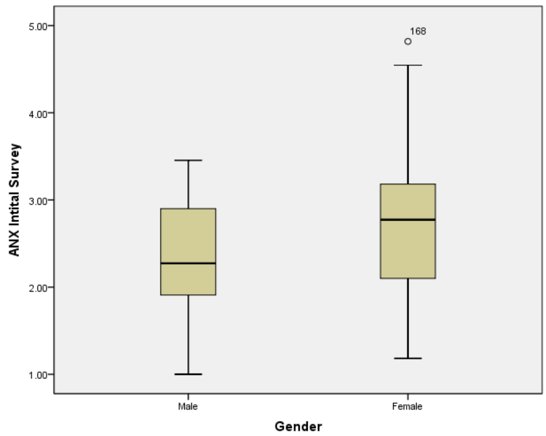

Figure 2: Boxplots of anxiety scores for males (left) and females (right) for the 2010 cohort.

Anxiety between the two cohorts over the two subscales as well as the 11-item modified AMAS was remarkably similar, except that scores of males over the 11-item modified AMAS differed significantly between the two cohorts (pkw=0.014). Boxplots revealed that males in 2011 scored higher than males in 2010. This may help explain the lack of significant difference between males and females in 2011.

Students' anxiety levels were not found to have any dependence on their first language, domestic/international status or years since leaving school.

Anxiety and performance

We used stepwise forward regression models separately for the two cohorts to examine the relationship between students' final scores, invigilated class tests scores, and anxiety. Since there were two clear, well-defined factors – MEA and MLA – underpinning anxiety, we considered them each as predictor variables in the regression model. We extended the regression analyses to include quadratic terms of both and all first order interactions with gender and preferred discipline, being the two demographic variables that we showed to affect anxiety. The results of the regression analyses are shown in Table 3.

Table 3: Results of stepwise forward regression models. The dependent variable (Y) is the performance score in those invigilated assessments the scores of which are significantly affected by independent variables. Independent variables are as follows: X_1(MLA), X_2(MEA), Z_1(preferred discipline) where Z_1=1 for the maths-physical sciences group and zero otherwise, Z_2(gender) where Z_2=1 for males and zero otherwise.

Cohort	Dependent variable (Y)	Regression equation	p	R^2adj
2010	Final score	$Y = 65.345 - 4.780(X_2^2)$	0.009	0.047
	Class test	$Y = 21.376 + 7.886(Z_1)$	0.001	0.081
	Exam total	$Y = 37.442 + 13.035(Z_1)$	0.034	0.029
	Exam theory	$Y = 22.576 – 4.739(Z_2X_1) + 7.027(Z_1)$	0.004	0.079
	Exam practical	$Y = 19.582 +5.256(Z_1) - 1.645(X_2^2)$	0.013	0.055
2011	Class test 1	$14.664 – 0.775(X_2)$	0.026	0.028
	Class test 2	$12.568 – 2.694(Z_1X_2) - 1.670(Z_1X_1)-0.670(X_2)$	<0.005	0.147
	Class test 3	$12.971 – 1.084(Z_2X_2)$	0.045	0.022

Anxiety significantly affected performance of the 2010 cohort in both the theory and practical sections of the final examination as well the overall performance in the subject. Using up to second order linear models we identified significant quadratic relationships between MEA and performance in the practical examination and students' final score (Figure 3). Performance in the 2010 theory examination was influenced by an interaction between gender and MLA with the main effect due to preferred discipline. The only factor affecting performance in the 2010 class test was preferred discipline with the maths-physical sciences group scoring higher in the class test than the biological/earth/environmental sciences group.

Among the 2011 cohort no relationship between any of the independent variables and students' final score or the scores of the final examination was demonstrated. However, we identified significant relationships between the three class test scores and anxiety subscales, gender, preferred discipline and interaction terms. Generally, increasing anxiety caused a linear decline in performance on these invigilated assessment items.

Students scoring higher on anxiety (MEA) tended to score lower in the first class test. Key variables that influenced scores on the second class test were an interaction between major and MEA coupled with an interaction between major and MLA and a main effect due to MEA. Although the math-physical sciences group tended to outperform the biological/earth/environmental sciences group, those maths-physical sciences students scoring on the higher end of the MEA subscale performed poorer on the second class test than similarly anxious students in the biological/earth/environmental sciences group. Scores on the third class test were influenced by an interaction between MEA and gender. Male test scores declined more than female scores with increasing anxiety on the MEA subscale (figure 4).

Although these regressions were significant, the R^2adj were very low and explained less than 1% of the total variability. However we were not using the model for predictive purposes but rather to better understand how mathematics anxiety may affect performance from a conceptual standing.

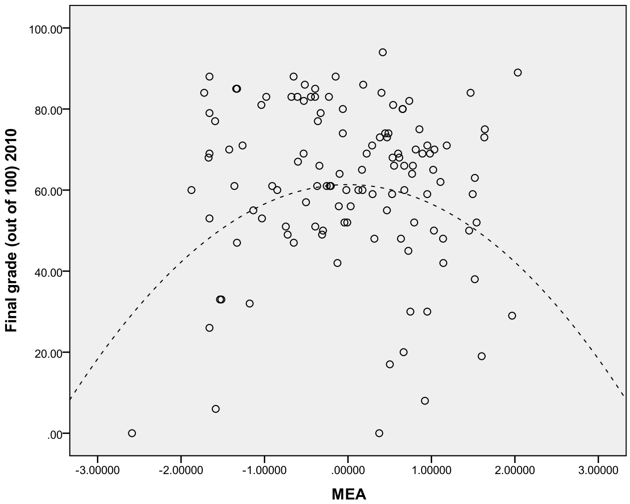

Figure 3: Quadratic relationship between 2010 final grade and anxiety – MEA subscale (from Gyuris and Everingham 2011).

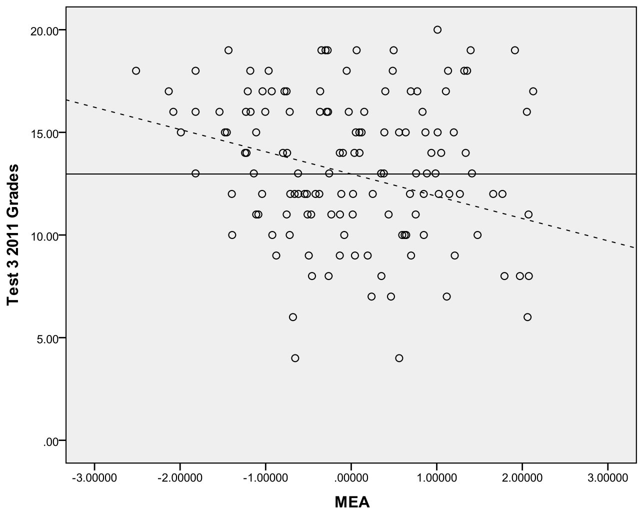

Figure 4: Relationship between MEA and performance on class test 3, 2011. Solid line – female, dashed line – male.

Discussion

The current study enhances the findings of Gyuris & Everingham (2011) and confirms that maths evaluation anxiety and preferred major as factors most frequently influencing student performance in invigilated assessments. Gender and maths learning anxiety were less frequently correlated with performance. In this study, restricted to our Townsville campus, we removed uncontrolled variables that were present in the earlier study (Gyuris & Everingham, 2011) arising from differences between campuses in the teaching team and assessment conditions, inevitable when dealing with multi-campus institutions.

In 2010, student achievement in each invigilated assessment was affected by anxiety and/or by preferred major, a demographic variable that was correlated with anxiety. Achievement in both the final subject score and in the practical examination was shown to have a quadratic relationship with maths evaluation anxiety (MEA) and preferred major was a significant independent variable, alone or in interaction with MEA or MLA, affecting performance in all but the final score for the subject. In 2011, significant linear relationships between performance and anxiety, preferred major and gender were identified with the three class tests only. The final score for the subject, the interim final scores and scores for final examination showed no significant relationship with any of the predictor variables.

Keeley et al. (2008) found that correlation between performance and anxiety, when demonstrated, tended to be linear for the assessments administered earlier in the semester and curvilinear for later assessments. They assumed that this change in the relationship between performance and anxiety might be a response to the increasing level of difficulty of consecutive assessments. Ashcraft and Moore (2009) were able to differentiate between diminished math performance either as the result of anxiety or as the result of lower competence in mathematics. Thus, according to their model, when required to perform in pressure inducing, high-stakes test situations, individuals with a predisposition to anxiety will achieve lower test scores than they would while performing the same cognitive challenge in a less intense situation. We infer that, taken together, these two studies imply that mathematical competency or high mathematics self-efficacy buffers against the effects of anxiety: Hence the linear relationship between anxiety and performance on class tests. However when required to perform in pressure inducing, high-stakes test situations, such as final end of year examinations, those competent students that have a predisposition to anxiety will no longer be buffered and will experience a drop in performance – hence the observed quadratic relationship between MEA and performance as found amongst the 2010 cohort.

Our results concur with this inference. In 2010 the class test completed in week eight and weighted at 20% of the final mark had a linear relationship with preferred discipline: those students having a preference for maths-physics performed significantly better than other students and neither anxiety subscale could be shown to influence performance scores. However, with the high-stakes final examination MEA^2 and MLA were significant factors affecting performance. Students would see the final examination as a pressure inducing, high-stakes situation: It contributed 50% toward the final grade, was conducted in an unfamiliar, highly formal setting, invigilated by unfamiliar personnel and most students would have been unaccustomed with taking a practical examination requiring mathematical skills. Students scoring towards the high and low ends of the MEA subscale at the start of the semester tended to perform more poorly, and students with mid-level anxiety tended to perform the better, presumably more closely reflecting their true competency.

In 2011 we revised our assessment schedule, partly in response to student feedback and partly to Ashcraft and Moore's (2009) cautioning about the fallacy of taking the results of high-stakes assessments performed in high pressure settings as a true reflection of a student's mastery of mathematics. Our three class tests were weighted at 30% each, were completed in a familiar setting, and we made clear to students that poorer performance in one test can be offset with higher achievement in the other tests. Consequently, and as predicted by Keeley et al. (2008) and the model of Ashcraft and Moore (2009), only linear relationships were identified between test scores and the independent variables. Generally, achievement in the tests declined linearly with increasing scores on MEA or MLA subscales, although in the second and third tests preferred major and gender modified the relationship between performance and anxiety.

In 2011 those students who performed relatively weakly on the on-course assessment took the final examination. Remarkably few students above the 65% cutoff, and for whom the examination was optional, chose to sit for the final examination. It is therefore most likely that those sitting the examination were a highly select group and, unlike in 2010, no significant correlation was demonstrated between anxiety and performance in that examination nor did either anxiety subscale affect the final grade.

Thus, there is accumulating evidence that anxiety and performance in higher stakes, summative assessments of mathematics and statistics follows a curvilinear relationship whereas in early or lower stakes assessments a linear relationship may be more common.

Summary and conclusions

Our objective was to establish a baseline understanding of factors affecting mathematics anxiety of first year science students at a regional university. We found that our student populations were remarkably homogeneous with respect to the mathematics anxiety they experienced. Students who preferred the maths-physical sciences were consistently and significantly less anxious overall than students preferring other disciplines. Gender was associated with maths anxiety in 2010 but not in 2011.

We also investigated whether students' anxiety at the start of a compulsory quantitative skills subject had a significant effect on performance in the subject. While we identified several significant relationships between anxiety subscales, preferred discipline, gender and student performance, R^2adj was consistently very low revealing that maths anxiety was not a useful predictor of performance.

Finally, we observed the effect that assessment schedules may have on the relationship between anxiety, in particular anxiety associated with maths evaluation, and performance. This is an area of notable importance and interest and remains a challenge to investigate empirically, considering the ethical and logistical implications of suitably randomized manipulative experiments.

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