The Role of Mathematics Anxiety and Attitudes in Adolescents' Intentions to Study Senior Science

Erin Mackenzie
Western Sydney University
e.mackenzie@westernsydney.edu.au

Kathryn Holmes
Western Sydney University
k.holmes@westernsydney.edu.au

Nathan Berger
Western Sydney University
n.berger@westernsydney.edu.au

In this study, we examined whether generalised mathematics anxiety, application of mathematics in science anxiety, and positive attitudes towards mathematics influenced adolescents' intentions to study biology, chemistry, and physics in Grades 11 and 12. Participants were 477 students in Grades 8–10 from two schools in Western Sydney. Girls reported higher levels of generalised mathematics anxiety and application of mathematics in science anxiety. Positive attitudes towards mathematics were a significant and positive predictor of students' intentions to study all science subjects, while application of mathematics in science anxiety was a negative predictor of students' intentions to study chemistry and physics.

The capacity to understand and apply mathematics is important for learning and comprehension of most science subjects and can act as a gatekeeper for student participation in science in the senior years of schooling and beyond (Douglas & Attewell, 2017; Shapka et al., 2006). Student attitudes, both positive and negative, towards mathematics and their prior achievement in mathematics can influence intentions to study science-based courses post-school (Lin et al., 2017; Sass & Kampa, 2019). For girls in Australia, there is evidence that their perceived ability in mathematics has an impact on their intentions to study physics, chemistry and biology in the senior years of schooling and beyond (Mackenzie et al., 2021; Watt et al., 2017). There is also evidence that positive attitudes to both mathematics and science is associated with higher achievement in each subject, further reinforcing the important relationship between student attitudes in both subjects (Berger et al., 2020).

Unlike other school subjects, mathematics has a long-held reputation as being a difficult subject to master and for inducing anxiety in some students (Hill et al., 2016). Mathematics anxiety has been defined as a negative reaction to mathematics and to mathematical situations (Ashcraft & Ridley, 2005). Mathematics anxiety is related to other types of anxiety, for example, general and test anxieties, but is also distinct and specific to learning and doing mathematics (Dowker et al., 2016). Numerous studies have documented the widespread prevalence of mathematics anxiety (Ashcraft, 2002; Hembree, 1990; Maloney & Beilock, 2012) and its negative correlation with mathematics performance (Barroso et al., 2020; Ma & Kishor, 1997; Miller & Bichsel, 2004). However, less is known about the impact of negative attitudes to mathematics on student interest in studying closely related subjects such as science. Mathematics plays a central role in the conduct of science by offering tools to help quantify, model, and represent scientific phenomena (Dierdorp et al., 2014). However, there is evidence that many students struggle to apply mathematics in science subjects (Rebello et al., 2007; Redish, 2017).

Higher levels of mathematics anxiety are related to poorer mathematics performance for both boys and girls, but because girls' mean mathematics anxiety is generally higher than boys, they are potentially more at risk as anxiety levels increase (Hyde et al., 1990; Stoet et al., 2016). There is also recent evidence that mathematics anxiety varies across mathematical tasks, with greater anxiety experienced by girls on mathematics tests but not during coursework (Geary et

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al., 2020). Therefore, the extent of mathematics anxiety felt at any particular time is highly dependent on the context within which mathematics is being experienced.

For this paper, we were interested in examining if domain-specific anxiety connected to 'applying mathematics in science', separately or simultaneously with generalised mathematics anxiety, was related to students' intentions to study senior science. Mathematics anxiety levels vary depending on the context within which the mathematics is being experienced, therefore, it is important to examine its impact on student subject choice across science subjects so that students can be better supported in pathways to further science study and careers. Participation in science subjects has persistent gendered patterns, with girls more likely to study biology, rather than physics (Yu & Warren, 2018). Given the higher rates of mathematics anxiety prevalent amongst girls, it was also important to examine how this anxiety was related to the intention to study different science subjects by gender.

While mathematics anxiety levels were of particular interest in this paper, we were also interested in how positive attitudes towards mathematics were related to intentions to study science. Positive attitudes towards mathematics encompasses students' enjoyment and valuing of mathematics, including their perceived relevance of mathematics. A significant body of research supports the notion that students who have positive attitudes towards a subject are more likely to continue studying it (Hsieh & Simpkins, 2022). We have previously found that, for most students, attitudes in mathematics and science were mirrored, with students demonstrating similar levels of confidence, liking, and valuing in both subjects (Berger et al, 2020). Also, there is evidence that students' attitudes to mathematics in early secondary school can subsequently impact on STEM course enrolments in the later years of schooling (Jiang et al., 2020). Indeed, students who are open to mathematics but not science have amongst the lowest STEM career expectations (Hsieh & Simpkins, 2022). However, it is less clear how positive attitudes towards mathematics influence students' science subject selections in the different science strands. Therefore, we examined the relationship between positive attitudes to mathematics and intentions to study science alongside our investigation of mathematics anxiety in relation to the study of science subjects.

Method

Participants

Participants were 477 students in Grades 8 (n = 193), 9 (n = 138), and 10 (n = 146) drawn from two single-sex, independent schools in Western Sydney. Female students were overrepresented in the sample (324 female, 153 male, 1 non-binary). 0.6% of the sample identified as being of Aboriginal and/or Torres Strait Islander descent. 60.8% spoke only English at home, while 34.4% spoke English at home in combination with another language and 4.8% did not speak English at home. 71.2% of the sample reported that their mother's highest level of education was a university degree, while 65.6% reported that their father's highest level of education was a university degree. Of the sample that began the survey (n = 477), 36 did not complete the measures of interest for this paper, leaving a final sample of 441 students.

Measures

Mathematics anxiety. Generalised mathematics anxiety was measured using the eight-item Negative Affect subscale of the *Mathematics Anxiety Scale–Revised* (MAS-R; Bai et al., 2009). The MAS-R has been validated for use with adolescent populations, demonstrating adequate validity and reliability (Bai, 2011). A sample item was: *I worry about my ability to solve math problems.* Participants were asked to identify how much they agreed with each statement on a scale from 1 (strongly disagree) to 5 (strongly agree), and scores were added to determine a

total score for the subscale. The scale demonstrated excellent reliability in this sample, α = 0.90.

Application of mathematics in science (AMS) anxiety. Three items, designed for this study, were used to measure participants' domain-specific anxiety surrounding the application of mathematical skills and concepts in science. The three items were: *How anxious do you feel when you have to use mathematical concepts during lab activities in biology* (e.g., working out the magnification when using a microscope)?, *How anxious do you feel when you have to use mathematical concepts during lab activities in chemistry* (e.g., drawing a graph of time vs. temperature for a chemical reaction)?, and *How anxious do you feel when you have to use mathematical concepts during lab activities in physics* (e.g., using a formula to work out an unknown value)? Students were asked to respond to each item on a scale from 1 (not at all anxious) to 4 (very anxious), and responses were averaged to form a scale score. The scale demonstrated good reliability, α = 0.89.

Positive attitudes towards mathematics. Positive attitudes towards mathematics were measured using the Positive Affect subscale of the MAS-R (Bai et al., 2009; Bai, 2011). This six-item subscale includes items that reflect positive attitudes towards mathematics, such as: *I enjoy learning with mathematics* and *Math relates to my life*. Participants were asked to identify how much they agreed with each statement on a scale from 1 (strongly disagree) to 5 (strongly agree), and scores were added to determine a total score for the subscale. The scale demonstrated excellent reliability in this sample, α = 0.90.

Intentions to study senior science subjects. Three items measured participants' intentions to study biology, chemistry, and physics in Years 11 and 12. Participants were asked to rate how likely they were to study these subjects using a scale from 1 (very unlikely) to 5 (very likely).

Procedure

This study received institutional ethics approval and principal approval from each school prior to implementation. All students in Grades 8, 9, and 10 from each school were invited to participate. Standing parental consent was used in this study. Parents provided permission at the beginning of the year for their child to participate in research projects approved by the school throughout the year. Parents were then notified about the study and were given a two-week period to indicate that they did not consent for their child to participate in the study. Parents could also "opt in" to the study if they had not previously given permission for their child to participate in school research projects. Students were also asked to indicate whether they wanted to participate in the study, with a question included in the online survey that allowed them to withdraw from the study if desired. Study participation involved students completing a 25-minute online survey in class time. The response rates for the two schools were substantially different: 57.3% at the girls' school and 17.7% at the boys' school.

Results

Analyses were conducted using IBM SPSS Version 27. Except where otherwise noted, statistical significance was set at $p < 0.05$.

Descriptive Statistics and Correlations

Descriptive statistics for all study variables are shown in Table 1. Girls had significantly higher mathematics anxiety than boys with a small effect size, $t(438) = -2.65$, $p = 0.008$, $d = 0.28$. Girls also had significantly higher AMS anxiety than boys with a small effect size, $t(287.56) = -3.55$, $p < 0.001$, $d = 0.35$. However, there was no significant difference in positive

attitudes towards mathematics between the genders, $t(438) = 1.07$, $p = 0.29$, $d = 0.11$. Girls were less likely to report they intended to study physics in the senior years, $t(436) = 5.23$, $p < .001$, $d = 0.55$, but there were no gender differences in students' intentions to study chemistry, $t(436) = 0.76$, $p = 0.45$, $d = 0.08$, or biology, $t(436) = -1.90$, $p = 0.06$, $d = 0.20$.

Table 1
Descriptive Statistics for Entire Sample and by Gender

Variable	Range	Entire sample			Girls			Boys		
		N	*M*	*SD*	*n*	*M*	*SD*	*n*	*M*	*SD*
Mathematics anxiety	5–40	441	23.52	7.37	307	24.12	7.28	133	22.11	7.42
AMS anxiety	1–5	440	2.00	0.90	307	2.09	0.93	132	1.78	0.80
Positive attitudes towards mathematics	5–30	441	20.39	6.04	307	20.17	6.05	133	20.84	6.02
Intentions to study biology	1–5	439	3.30	1.45	308	3.39	1.46	130	3.10	1.40
Intentions to study chemistry	1–5	439	3.10	1.44	308	3.06	1.47	130	3.18	1.38
Intentions to study physics	1–5	439	2.64	1.40	308	2.43	1.35	130	3.17	1.39

Correlations for all study variables are shown in Table 2. There was a large positive correlation between mathematics anxiety and AMS anxiety ($r = 0.53$, $p < 0.001$). Mathematics anxiety was moderately negatively correlated with positive mathematics attitudes ($r = −0.44$, $p < 0.001$). There was also a moderately negative association between positive mathematics attitudes and AMS anxiety ($r = −0.45$, $p < 0.001$). Positive attitudes towards mathematics were moderately positively correlated with intentions to study chemistry ($r = 0.44$, $p < 0.001$) and physics ($r = 0.41$, $p < 0.001$) but the association with intentions to study biology was small ($r = 0.13$, $p = 0.005$). Mathematics anxiety had a *small* negative association with chemistry intentions ($r = −0.19$, $p < 0.001$) and physics intentions ($r = −0.20$, p <0 .001); but the association between AMS anxiety was *moderately* negative with chemistry intentions ($r = −0.32$, $p < 0.001$) and physics intentions ($r = −0.34$, $p < 0.001$). While there was a large positive correlation between physics intentions and chemistry intentions ($r = 0.49$, $p < 0.001$), the correlation between physics intentions and biology intentions was small ($r = 0.11$, $p = 0.03$).

Table 2
Correlations Between Study Variables

Variable	1	2	3	4	5	6
1. Mathematics anxiety	—	.53**	−.44**	.01	−.19**	−.20**
2. AMS anxiety	.53**	—	-.45**	−.08	−.32**	−.34**
3. Positive attitudes towards mathematics	−.44**	−.45**	—	.13**	.44**	.41**
4. Intentions to study biology	.01	−.08	.13**	—	.44**	.11*
5. Intentions to study chemistry	−.19**	−.32**	.44**	.44**	—	.49**
6. Intentions to study physics	−.20**	−.34**	.41**	.11*	.49**	—

Note. ** = Correlation is significant at the 0.01 level (2-tailed). * = Correlation is significant at the 0.05 level (2-tailed).

Regressions

We conducted three regressions to examine the relative contribution of gender, mathematics anxiety, AMS anxiety, and positive attitudes towards mathematics to students' intentions to study biology, chemistry, and physics in the senior years of high school. All predictors were entered simultaneously, and results are shown in Table 3.

Table 3
Regressions Predicting Intentions to Study Biology, Chemistry, and Physics in the Senior Years of High School

Predictor	Biology intention			Chemistry intention			Physics intention		
	B	*SE*	β	*B*	*SE*	β	*B*	*SE*	β
Gender	.29	.15	.09	.01	.14	.00	-.64	.13	-.21***
Mathematics anxiety	.02	.01	.11	.02	.01	.09	.02	.01	.08
AMS anxiety	-.15	.09	-.10	-.31	.08	-.19***	-.31	.08	-.20***
Positive attitudes towards mathematics	.03	.01	.13*	.09	.01	.39***	.08	.01	.34***
R^2		.03			.22			.24	
F for change in R^2		3.70**			29.37***			34.13***	

Note. * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$

The regression predicting intentions to study biology was significant but accounted for a very small proportion (3.3%) of the variance, $R^2 = 0.03$, $F(4, 430) = 3.70$, $p = 0.006$. The only significant predictor was positive attitudes towards mathematics (β = 0.13, $p = 0.02$). The regressions predicting intentions to study chemistry ($R^2 = 0.22$, $F(4, 430) = 29.37$, $p < 0.001$) and physics ($R^2 = 0.24$, $F(4, 430) = 34.13$, $p < 0.001$) were also significant, and accounted for a larger proportion of the variance (21.5% and 24.1% respectively). AMS anxiety was a negative predictor of students' intentions to study chemistry (β = -.19, $p < 0$ .001) and physics (β = -0.20, $p < 0.001$), while positive attitudes towards mathematics was a positive predictor of students' intentions to study chemistry (β = 0.39, $p < 0.001$) and physics (β = 0.34, $p < 0.001$). General mathematics anxiety was not a significant predictor of students' intentions to study any science subjects, and gender was a significant predictor in the case of intentions to study physics only, such that boys were more likely to intend to study physics than girls (β = -0.21, $p < 0.001$).

Summary

In this study, girls had higher mathematics anxiety and AMS anxiety than boys. While girls were less likely to indicate an intention to study physics in senior high school, there were no gender differences for chemistry or biology. Mathematics anxiety and AMS anxiety were related constructs but had different relationships to other study variables. AMS anxiety appeared to be more predictive of intentions to study chemistry and physics than mathematics anxiety. Positive attitudes towards mathematics were a notable positive predictor of students' intentions to study all science subjects.

Discussion

Mathematics anxiety is a well-documented phenomenon in educational research with widespread incidence and negative impact on performance in the subject itself (Dowker et al., 2016; Miller & Bichsel, 2004). In our previous work, we have established various links between mathematics and science attitudes. For instance, liking, valuing, and confidence in mathematics was associated with similar attitudes in science (Berger et al., 2020). We have also shown that attitudinal constructs influence senior science subject choices (Mackenzie et al., 2021). In this study, we extend our understanding of the interrelationships between mathematics and science to the phenomenon of mathematics anxiety. In particular, because mathematics anxiety depends on the context within which mathematics is experienced, we explored whether generalised or domain-specific forms of mathematics anxiety were more

predictive of intentions to undertake chemistry, physics, and biology in the senior years of high school.

Girls frequently have higher levels of mathematics anxiety than boys (Stoet et al., 2016). The findings of our study extend that observation to a domain-specific form of mathematics anxiety. In addition to higher levels of generalised mathematics anxiety, the girls in this study also had higher AMS anxiety than boys. That is, girls were more likely than boys to report anxiety about scientific tasks that required the application of mathematical concepts, like using formulas and drawing graphs. This finding is concerning given that mathematics forms an integral part of most science disciplines (Douglas & Attewell, 2017) and science provides an applied avenue for the development of many mathematical concepts and skills (Berger et al., 2020).

An interesting, but somewhat surprising, finding was that generalised mathematics anxiety was not a significant predictor of students' intentions to study any of the science subjects in senior high school. While we observed a significant and negative correlation between generalised mathematics anxiety and intentions to study physics and chemistry, in the presence of other variables (positive attitudes towards mathematics and AMS anxiety), this relationship was no longer significant. This suggests that general mathematics anxiety minimally influences adolescents' attitudes and feelings towards learning in science. However, given the strong and positive relationship between generalised mathematics anxiety and AMS anxiety, we argue that the role of mathematics anxiety in adolescents' science subject selections warrants further investigation. For example, it is possible that generalised mathematics anxiety precedes more domain-specific mathematics anxieties. While outside the scope of this study, future research could investigate such temporal relationships via longitudinal research designs.

In this study, we observed that positive attitudes towards mathematics was a notable positive predictor of students' intentions to study all science subjects. This suggests that positive attitudes towards mathematics are more influential than mathematics anxiety in guiding students' intentions to study science. As previous research has found that students with higher mathematics than science motivation have greater STEM achievement and course taking in high school than students with higher science than mathematics motivation (Snodgrass Rangel et al., 2020), our finding supports an increased focus by teachers and parents on supporting adolescents' positive attitudes towards mathematics. Positive attitudes towards mathematics were more strongly related to intentions to study chemistry and physics in comparison to biology, which further reflects the greater congruence between mathematics and physics and chemistry (Jansen et al., 2015).

Practical Significance

There has been much focus in recent years on addressing gender inequities in participation in the STEM disciplines (Hsieh & Simpkins, 2022). Girls may need different activities to support their attitudes and intentions for mathematics and science, particularly where mathematics underpins the content being taught (Berger et al., 2020). Factors like domain-specific forms of mathematics anxiety present a possible avenue to improve the proportion and experience of girls in science. Mathematics and science teachers share the responsibility for addressing domain-specific forms of mathematics anxiety. Another avenue for improving domain-specific mathematics anxiety involves identifying the mathematical skills required in science to help students to make more explicit connections between the disciplines. This will require closer collaboration between mathematics and science faculties than traditionally has been the case in schools (Furner & Kumar, 2007). Finally, positive attitudes towards mathematics were the strongest predictor of students indicating an intention to study chemistry and physics. This reinforces the importance of supporting students to develop positive attitudes towards mathematics. Pedagogical interventions that emphasise the relevance and value of

mathematics, particularly in science, are a way to strengthen students' positive attitudes and motivation (Furner & Kumar, 2007).

Limitations and Conclusion

While this study extends our understanding of the role of mathematics anxiety and attitudes in adolescents' science subject selections, there are several limitations to note. First, our study focused on adolescents' *intentions* to study science, rather than their actual subject selections. It is possible that adolescents' subject selection intentions change over time, but we argue that there is value in considering their intentions as these indicate current interest and valuing of each subject. The second limitation to note is that our research design was cross-sectional, which does not allow for determination of the direction of effects. As stated previously, we recommend that future longitudinal designs are implemented to disentangle the relationships between variables considered in this study. A third limitation of our study was the relatively small response rate from the boys' school. Further research with different populations is needed to determine whether the relationships between mathematics anxieties and attitudes and science subject selections observed in this study are also present in adolescents from different school contexts.

This study makes an important contribution to the field by investigating how mathematics anxieties and attitudes influence adolescents' science subject selections. While generalised mathematics anxiety did not appear to influence intended subject selections, AMS anxiety and positive attitudes towards mathematics appear to be particularly influential in adolescents' intentions to study chemistry and physics. These findings have important practical implications for mathematics and science educators to support more students (particularly girls) in continuing their study of science in the senior years of high school.

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