GENDER AND MATHEMATICS: QUALITY AND EQUITY

Abstract

Over the past two decades, there have been no gender differences in mathematics achievement in Australia in large-scale international surveys such as the Trends in International Mathematics and Science Study (TIMSS). Similarly, when mathematical literacy was measured in the Programme for International Student Assessment (PISA) in 2003, there were no gender differences. However, PISA 2012 found that, while average scores in mathematics had declined in Australia, males in Australia were significantly outperforming females, and females had significantly higher average levels of anxiety about and significantly lower levels of confidence in mathematics. In light of the recent report of the Australian Council of Learned Academies, which points to an underrepresentation of women in science, technology, engineering and mathematics (STEM) careers in Australia, these trends are worrying, and point to the possibility of even fewer females progressing into these areas. This paper unpacks the PISA 2012 data to further investigate the achievement, attitudes and beliefs of young Australian females and males about mathematics. For whom is Australia providing a quality education in mathematics, and to what extent is this provided in an equitable way? It is hoped that a more differentiated view of the achievement, attitudes and beliefs of both males and females will assist governments in making policy decisions that will encourage participation and higher levels of achievement for females.

Sue Thomson

Australian Council for Educational Research

Dr Sue Thomson is the Director of the Educational Monitoring and Research Division at ACER and a Chief Investigator in the Science of Learning Research Centre, in which ACER is a lead institution. She is also the Research Director for the National Surveys research program at ACER, overseeing Australia's participation in all international and national sample surveys.

Dr Thomson has also fulfilled the roles of National Research Coordinator for Australia in the International Association for the Evaluation of Educational Achievement (IEA) Trends in International Mathematics and Science Study (TIMSS) since 2002, National Project Manager for Australia in the OECD Programme for International Student Assessment (PISA) since 2004, and National Research Coordinator for Australia in the IEA Progress in International Reading Literacy Study (PIRLS) since 2008. In these roles she has contributed to the development of the instruments and questionnaires, particularly for TIMSS, for which she is a member of the Questionnaire Review Committee.

Dr Thomson's research at ACER has involved extensive analysis of large-scale national and international data sets – the Longitudinal Surveys of Australian Youth (LSAY), as well as TIMSS and PISA – and she is also involved in several projects involving analysis of the longitudinal data collection associated with the PISA surveys. She was engaged as an expert writer on the National Numeracy Review, and has consulted with a variety of government departments at both Commonwealth and state levels, as well as with the Catholic Education Commission, on a variety of data-analysis projects related to TIMSS and PISA.

The role of schools in preparing students for further study that will lead to future employment is an important one. However, while it has been estimated that 75 per cent of the fastest growing occupations require skills and knowledge in science, technology, engineering and mathematics (STEM) fields, a recent research report from the Australian Industry Group reveals what they describe as 'a disturbing picture in this area'. The report argues that young people in schools and universities are not acquiring the STEM skills we need for our future prosperity (Australian Industry Group, 2013). By increasing the proportion of students who stay in STEM through senior secondary school into university, including women and low socioeconomic status (SES) students, it is possible for a country to expand the talent pool from which future STEM high achievers will be drawn (Australian Council of Learned Academies (ACOLA), 2013, p. 14).

Unfortunately, the percentage of Year 12 students enrolled in higher level STEM in Australia has been declining for decades. Over the period 1992–2010, the proportion of Year 12 students in biology fell from 35 to 24 per cent, in chemistry from 23 per cent to 17 per cent, and in physics from 21 to 14 per cent (Office of the Chief Scientist, 2012, p. 43). The decline in the proportion of students enrolled in mathematics was not as sharp, dropping from 77 per cent to 72 per cent, but most students were enrolled in elementary mathematics subjects. Only 10 per cent participated in advanced mathematics at Year 12 level, with 20 per cent in intermediate mathematics. A growing proportion of high-achieving Year 12 students, particularly female students, participate in no mathematics at all.

Further, girls and women are less likely to choose careers in STEM areas, and more likely than males to drop out when they do enter those fields. This pattern has been called the 'leaky pipeline' (Watt, Eccles & Durik, 2006). Nonetheless, it is vital that we encourage girls and women to participate in STEM careers. Not only are jobs in such areas more likely to be better paid and more stable, but scientists and engineers work to solve some of the most difficult challenges of our time, and engineers design many of the things we use daily. When women are not involved in science and engineering, their unique experiences, needs, and desires may be overlooked, and the perspectives that these experiences may add to the body of scientific knowledge are lost. As an extreme example of this, a predominantly male group of engineers tailored the first generation of airbags in motor vehicles to suit adult male bodies, resulting in avoidable deaths for women and children (Margolis & Fisher, 2002, pp. 2–3).

Over the past four decades, there has been a steady stream of research on gender differences in mathematics, with the focus on discovering the reasons for females not participating in mathematics at the same levels as males. In one of the seminal studies in the area, Fennema and Sherman (1977), found that when two factors – the number of prior mathematics courses taken and experience with spatial activities – were taken into account, there were no statistically significant gender differences in abilities in mathematics. The researchers also found that males generally had more positive attitudes towards mathematics.

A large number of research studies over the intervening years have focused on affective and attitudinal variables and their impact on females' decision to continue studies in higher mathematics and science. Identified as critical are beliefs about the usefulness of mathematics and confidence in learning mathematics, with males generally indicating higher levels of confidence in learning mathematics than females, and males believing that mathematics was, and would be, more useful to them than did females. The importance of these variables, their long-term influence and their differential impact on females and males has been reconfirmed in many studies (Leder, 1992). In a study of participation in senior higher mathematics, Watt, Eccles and Durik (2006) also found that the strongest influence on maths participation for both males and females was the extent to which they were interested in and liked maths. This influence was stronger than that of their prior demonstrated mathematical achievement. A secondary factor was students' self-perceptions about their own maths talent and their expectations for mathematical success, particularly for females (p. 653).

Gender differences in mathematical literacy

Over the past two decades, the only significant gender difference in mathematics achievement in Australia in the Trends in International Mathematics and Science Study (TIMSS) was in 2007, and females' scores have recovered since then to show no gender difference in TIMSS 2012. Similarly, when mathematical literacy was measured in the Programme for International Student Assessment (PISA) in 2003, there were no gender differences; however, the most recent full assessment of mathematics in PISA 2012 found that while average

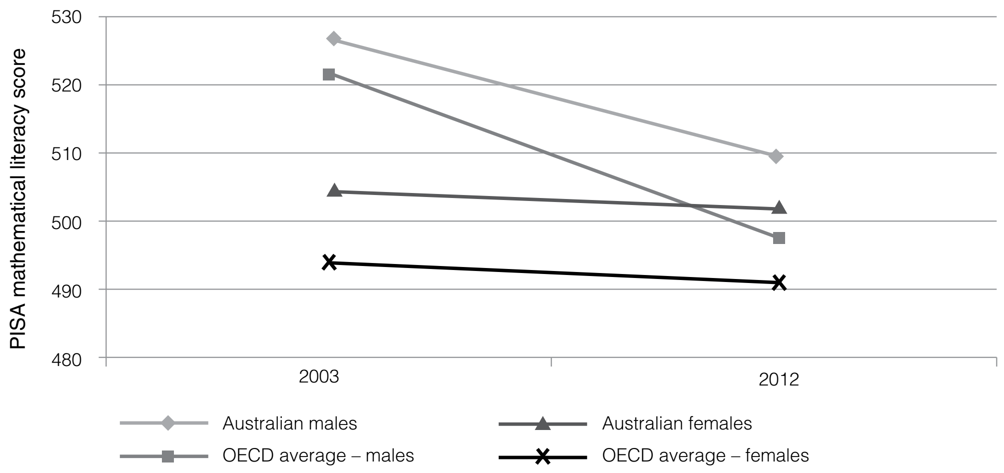

Figure 1 Scores for Australian males and females, and OECD averages for mathematical literacy, PISA 2003 and 2012

scores for both males and females had declined significantly, the average for females had declined more, and males in Australia were significantly outperforming females (Figure 1). While the difference is not great, it is important. Also important is that the average score for Australian females has declined to the extent that is now not significantly different from the OECD average score.

Analysis

A number of attitudinal variables that were used in PISA 2003 and PISA 2012 were also examined to see whether the differences in students' scores were reflected in differences on these variables. All of the variables were standardised to an average over the OECD of 0 and a standard deviation of 1.

- SELFCON. Students' self-concept in mathematics was measured from responses on a four-point Likert scale (strongly agree, agree, disagree, strongly disagree) to a number of items such as 'I get good grades in mathematics', 'I learn mathematics quickly', 'I am just not good at mathematics' (reversed).
- ANXMAT. Anxiety about mathematics was measured from responses on a four-point Likert scale (strongly agree, agree, disagree, strongly disagree) to items such as 'I often worry that it will be difficult for me in mathematics classes', 'I get very nervous doing mathematics problems', 'I feel helpless when doing a maths problem'.
- INSTMOT. Instrumental motivation was measured from responses on a four-point Likert scale (strongly agree, agree, disagree, strongly disagree) to items such as 'Making an effort in mathematics is worth it because it will help me in the work that I want to do later on', and 'I will learn many things in mathematics that will help me get a job'.
- INTMAT. Interest in mathematics, measured from responses on a four-point Likert scale (strongly agree, agree, disagree, strongly disagree) to items such as 'I look forward to my mathematics lessons' and 'I do mathematics because I enjoy it'.
- MATHEFF. Mathematics self-efficacy. Students' rating of their confidence in doing a number of mathematical tasks, such as 'understanding graphs presented in newspapers' and 'solving an equation such as $3x + 5 = 17$'.

Figure 2 summarises the attitudinal data for these variables, separately for males and females for 2003 and 2012.

This figure tells a number of interesting stories. For males, there have been very few changes in attitudes between PISA 2003 and PISA 2012. Self-concept in mathematics, instrumental motivation and mathematics self-efficacy were all significantly higher than the OECD average in 2003 and remained around the same level in 2012. Interest in mathematics, already significantly higher than the OECD average in 2003, increased significantly between 2003 and 2012. Anxiety about mathematics, on the other hand, already significantly lower than the OECD average in 2003, remained at about the same level in 2012.

For female students, the story is completely different, and in general could be summarised as poorer in 2012 than in 2003. Self-concept in mathematics, not significantly different from the OECD average in 2003, declined to

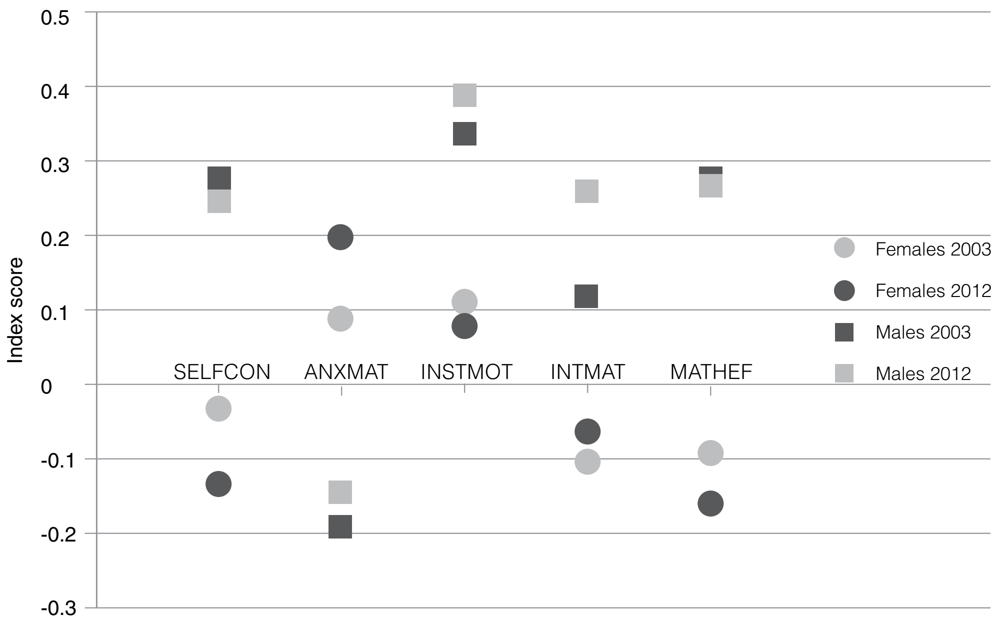

Figure 2 Attitudes to mathematics, by gender over time

be significantly lower than the OECD average in 2012. Anxiety about mathematics was significantly higher than the OECD average in 2003 and increased to be even higher in 2012. Interest in mathematics was lower than the OECD average in both 2003 and 2012, as was mathematics self-efficacy. The only bright spot was that the scores for instrumental motivation were significantly higher than the OECD average in both 2003 and 2012 and there was no decline – female students could see, although not as strongly as male students, that mathematics would be useful for them in their later lives.

Multiple regression analysis was conducted so that the individual effects of each of these attitudes could be examined while accounting for the effects of the others. This model accounted for 39 per cent of the variance in mathematics achievement of female students, and 35 per cent of the variance in mathematics achievement of male students. Table 1 contains adjusted effects and standard errors resulting from these models. Interest in mathematics was omitted from the final model due to collinearity with instrumental motivation.

As can be seen from Table 1, the strongest predictor of achievement for both males and females was mathematics self-efficacy, which showed an effect of 47 score points for females and 44 score points for males. The next strongest predictor for females was self-concept in mathematics, whereas for males this variable was not a significant influence on mathematics achievement. Instead, for males, the next strongest predictor was mathematics anxiety, which was surprisingly not a significant influence on the mathematics achievement of females.

Discussion

Between PISA 2003 and PISA 2012, in which mathematical literacy was the major focus, the achievement scores in mathematics for Australian male and female students declined significantly, more so among females than males. As a result, there are significant gender differences in mathematics in Australia for the first time in several decades. Further analysis was conducted using a number of attitudinal variables available in both years.

This analysis showed that there are subtle, but perhaps important, differences between the influences on the achievement of males and females. For both groups of students, mathematics self-efficacy had the strongest relationship with achievement – those students who believe that they are capable of tackling mathematics problems in everyday life were more successful in undertaking the PISA mathematics assessment items. Of course, it is likely that this relationship is reciprocal, with students who are stronger in mathematics being aware that this is the case, and so more likely to strongly agree with these statements. At the same time, higher levels of self-belief may lead these students to tackle more difficult problems and thus develop their mathematics abilities to a greater extent. Given

Table 1 Results from multiple regression models

	Change in mathematics score per unit increase of the index			
	Females		Males	
	Effect	SE	Effect	SE
MATHEFF	47	2.3	44	2.8
SELFCON	21	3.7	5	3.8
INSTMOT	6	1.9	6	2.8
ANXMAT	–3	2.9	–16	3.2

Note: SE – standard error

the strength of the relationship between mathematics self-efficacy and achievement, the significant decline in self-efficacy reported by females between 2003 and 2012 is a concern.

The finding here that neither interest in mathematics nor instrumental motivation in mathematics added to the explained variance in achievement for either males or females is of note, given previous attention paid to both of these factors as important influences on engagement with and achievement in mathematics. It could be hypothesised that students who had low levels of skills in mathematics (and were aware of this limitation) were unlikely to express an interest in the subject or in pursuing it further, and that while students may be told that mathematics will be useful for them in later life they do not make the connection between that and doing well at mathematics. There may be a degree of cognitive dissonance involved in holding a belief that a subject that one does not do well in is important to one's future.

Further research into the interrelationship between these attitudes and their influence on mathematics achievement may prove integral in addressing the re-emergence of a gender gap in mathematics achievement in Australia. Focusing interventions on such factors as instrumental motivation and interest in mathematics may have little impact without addressing other key influences, identified here as self-concept in mathematics and mathematics self-efficacy. For Australia to succeed in increasing the achievement of female students in mathematics and, more broadly, female participation in STEM subjects, we need to be sure that we are targeting the most important factors in this equation.

References

Australian Council of Learned Academies. (2013). *STEM: Country comparisons: International comparisons of science, technology, engineering and mathematics (STEM) education.* Retrieved from http://www.acola.org.au/PDF/SAF02Consultants/SAF02_STEM_%20FINAL.pdf

Australian Industry Group. (2013). *Lifting our science, technology, engineering and mathematics (STEM) skills.* Retrieved from http://www.aigroup.com.au/portal/binary/com.epicentric.contentmanagement.servlet.ContentDeliveryServlet/LIVE_CONTENT/Publications/Reports/2013/Ai_Group_Skills_Survey_2012-STEM_FINAL_PRINTED.pdf

Fennema, E., & Sherman, J. (1977). Sex-related differences in mathematics achievement, spatial visualization, and sociocultural factors. *American Educational Research Journal, 14,* 51–71.

Leder, G. C. (1992). Mathematics and gender: Changing perspectives. In D. A. Grouws (Ed.), *Handbook of Research on Mathematics Teaching and Learning* (pp. 597–622). New York: Macmillan.

Margolis, J. & Fisher, A. (2002). *Unlocking the clubhouse: Women in computing.* Cambridge, MA: Massachusetts Institute of Technology.

Office of the Chief Scientist. (2012). *Health of Australian science.* Retrieved from http://www.chiefscientist.gov.au/wp-content/uploads/OCS_Health_of_Australian_Science_LOWRES1.pdf

Watt, H. M. G., Eccles, J. S., & Durik, A. M. (2006). The leaky mathematics pipeline for girls: A motivational analysis of high school enrolments in Australia and the USA. *Equal Opportunities International, 25*(8), 642–659.