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**Changing minds: Discussions in neuroscience, psychology and education**

The science of learning is an interdisciplinary field that is of great interest to educators who often want to understand the cognitive and physiological processes underpinning student development. Research from neuroscience, psychology and education often informs our ideas about the science of learning, or 'learning about learning'. However, while research in these three areas is often comprehensive, it's not always presented in a way that is easily comprehensible. There are many misconceptions about neuroscience, psychology and education research, which have been perpetuated through popular reporting by the media and other sources. These in turn have led to the development of ideas about learning and teaching that are not supported by research. That's why the Centre for Science of Learning @ ACER has launched the paper series, *Changing Minds: Discussions in neuroscience, psychology and education.*

The *Changing Minds* series addresses the need for accurate syntheses of research. The papers address a number of topical issues in education and discuss the latest relevant research findings from neuroscience, psychology and education. *Changing Minds* does not provide an exhaustive review of the research, but it does aim to provide brief syntheses of specific educational issues and highlight current or emerging paradigms for considering these issues across and within the three research fields. The paper series also provides teachers, school leaders and policymakers with accessible multidisciplinary theory and research that can be used to reflect on educational practice and policy.
Gender and sex differences in student participation, achievement and engagement in mathematics

Background

Gender differences in skills, behaviours and achievement are widely studied, however, the focus of the research varies greatly depending on the perspective of the researcher and the area studied. Research in neuroscience, psychology and education explores gender differences in achievement and learning in many different ways with different implications for educators and policymakers. This paper will present some of the literature from these three research fields. Rather than being an exhaustive review, the aim of this paper is to provide a brief synthesis of relevant issues when considering gender in education. This information can be used by members of the education community – whether that be teachers, school leaders or policymakers – to provide a greater understanding of the issue for reflection and to demonstrate the benefits of using multiple research perspectives for educational issues.

The paper has three main sections. The first section presents data on gender differences in mathematics participation, achievement and engagement in Australia. Note that for the purposes of this paper, the term ‘engagement’ will be used to describe students’ motivated involvement with mathematics, particularly in relation to motivational beliefs.

The second section of the paper presents research from neuroscience that delves into the issue of whether there are differences in the brain according to sex.

Finally, the third section of the paper discusses research from education and psychology that offer frameworks to conceptualise how gender differences in mathematics might develop.

A note on the terms ‘sex’ and ‘gender’. Generally in neuroscience, the term ‘sex’ is used to describe the biological differences between females and males while ‘gender’ differences are often used in psychological and educational research to encapsulate the social, cultural or environmental factors that could contribute to variation between females and males. In this paper, both sex and gender will be used depending on the area of research that is being discussed.

The problem with girls and mathematics in Australia

Participation

Mathematics is considered the gateway subject for academic development related to the fields of science, engineering, and mathematics (STEM) (Roberts, 2014) and given the current emphasis on increasing our STEM workforce in order to facilitate innovation (Australian Government, 2015), analyses of gender and mathematics are relevant to the national policy agenda. This is particularly the case given mathematics has a controversial past when it comes to female participation.

Unfortunately, national data show that the current picture of Australian female participation in mathematics is not encouraging. Australian research shows that while participation in maths and science subjects in secondary and tertiary education is decreasing overall, that there are further differences by gender. A study examining enrolments in the New South Wales High School Certification (HSC) over 2001 to 2011 found the number of students choosing to complete at least one maths and at least one science subject had decreased, however, the decline was greater for females students (3% compared to 1.1% for male students) (Wilson, Mack, & Walsh,
Further analysis included data from 2012 and 2013 and found that the number of students not studying any mathematics subjects for their HSC had tripled from 2001 to 2013 (Wilson & Mack, 2014). The biggest decrease in participation occurred for female students enrolled in an intermediate mathematics subject and a science subject. The authors also emphasised the small proportion of female students in 2013 (13.9%) who chose to study at least one mathematics subject and at least one science subject. Another study looking at national raw enrolment data collected by education departments from 1992 to 2012 found that male students across the time period were more likely to enrol in advanced mathematics subjects, with the total number of students choosing to pursue these subjects also declining (Kennedy, Lyons, & Quinn, 2014). Roberts (2014) reviewed enrolment in STEM subjects in Australia and also noted that the percentage of female students participating in Year 11 and 12 advanced and intermediate level mathematics was declining. She emphasised that completion of these subjects was necessary as a prerequisite for future mathematics study and careers in the area and that, therefore, this trend for female participation was troubling. In line with this, the OECD reported that only 31% of new entrants into bachelor degrees focusing on science and engineering (where mathematics study would be typically pursued) were female in 2013 (OECD, 2015). Together these statistics paint a concerning picture about the participation of females in mathematics subjects and courses in Australia.

![Percentage of new entrants into bachelor degrees in science and engineering in Australia, by gender](source: Education at a Glance (OECD, 2015))

**Achievement and engagement**

Participation data in mathematics reveal worrying trends concerning gender differences in educational outcomes, and it is not the only area to do so. A gender gap in mathematics achievement is also a problem in many education systems. In the United States, one study found that while there were no gender differences in mathematics achievement when children began school, after the first six years of school female students had lower achievement than male students (Fryer & Levitt, 2009). In Australia, when considering gender differences in performance or achievement data, results from the most recent cycle of the Programme for International Student Assessment (PISA) in 2012 are relevant. PISA measures the mathematics, science and reading literacy of more than half a million 15 year olds worldwide every three years. On average for 15-year-old Australian students, females achieved at a significantly lower level than male students, with a difference of 12 score points equating to being behind by approximately one-third of a school year (Thomson, DeBortoli, & Buckley, 2013). Interestingly, across the participating PISA countries, a similar pattern of males outperforming females was found in the majority of countries and in only three instances (in Thailand, Malaysia and Iceland) did females significantly outperform males. Further national analyses revealed that while 17% of Australian male students achieved at the higher proficiency levels for the PISA assessment, only 12% of Australian female students performed at this level.

The gender gap continues to affect students through an impact on students’ engagement with mathematics. PISA examined students’ attitudes towards mathematics and found that while approximately one-fifth of male students did not think mathematics was important for future study, approximately one-third of female students believed this statement (Thomson, DeBortoli, & Buckley, 2013). Female students also had significantly lower levels of self-
efficacy or confidence when it came to anticipating their success in completing particular mathematics tasks. In fact, the gap in mathematics self-efficacy scores between females and males was wider for Australian students than for students in Singapore, Canada and the United States. PISA results also showed that Australian female students reported significantly higher levels of mathematics anxiety than male students.

Other studies have demonstrated female disengagement in mathematics. Whereas self-efficacy relates to how confident an individual feels completing a particular mathematics task (e.g. I can solve the following equation), competence beliefs relate to an individual’s general beliefs about their capabilities in mathematics (e.g. I am good at maths). Research has demonstrated that gender differences in confidence extend beyond self-efficacy to more general competence beliefs, with Australian female students tending to perceive their general ability levels (competence beliefs) more negatively than male students (Nagy et al., 2010). A longitudinal, international study investigated gender differences in educational and career aspirations, participation in mathematics subjects and motivation towards mathematics in secondary school (Watt et al., 2012). The study found that levels of intrinsic value, or how much students enjoyed mathematics, were important in predicting Australian students’ educational aspirations towards mathematics. Unfortunately, the authors also found that Australian female adolescents had significantly lower levels of intrinsic value for mathematics. The researchers noted that the value student placed on maths had stronger implications for the educational aspirations of Australian students than those in the United States or Canada.

Together this evidence suggests that, on average, Australian female students are less engaged with mathematics and more fearful of the subject, less likely to pursue mathematics courses (particularly at higher levels), less likely to choose career pathways that involve mathematics and more likely to be outperformed by their male peers.

What does neuroscience tell us about brain differences between males and females?

Neuroscience research has shaped our understanding of what the brain can do, whether female and male brains operate differently and how such differences might influence learning. For instance, single-sex education has been validated citing evidence that ‘brain research’ has shown that learning is different for girls and boys (Eliot, 2013). Biological explanations have also been used in the past to describe poor female participation, engagement and achievement in mathematics. These explanations have suggested that fundamental differences in brain structure make females less capable in mathematics and less inclined to have an affinity for the subject. However, as we discuss in the second section of this paper, the growing consensus in neuroscience research is to move away from these types of arguments.
Structural differences

Neuroscience has examined sex differences and investigated specifically whether there are structural differences in the brain between females and males. It has been established that even after accounting for body size, males tend to have larger brains (Burgaleta, Head Alvarez-Linera, Martinez, Escorial, Haier, & Coom, 2012). Two centuries ago this was thought to be the factor contributing to males’ higher intelligence (Fine, 2012). This theory has been disproven and research is unclear as to the role of this increased brain volume (Burgaleta et al., 2012).

Newer research techniques, like functional magnetic resonance imaging (fMRI), have provided alternative methods for neuroscientists to investigate sex differences in the brain (Fine, 2013). This technology allows researchers to investigate more precisely whether there are differences in structure, connections and function between female and male brains. Some research suggests that there is evidence of this type of architectural variation between the sexes. A recent study with a sample of more than 900 participants, aged 9 to 22 years, found that male brains showed more connectivity within lobes of the brain and within each hemisphere and female brains showed more connectivity between the hemispheres (Ingalhalikar et al., 2014).

A reviewer of this work proposed that these findings demonstrated different wiring patterns between the sexes – male brains are more modular and function in a more localised manner while female brains are structured for interconnectedness – and that sex must then be an important consideration when trying to understand brain function (Cahill, 2014). On the other hand, other reviewers have questioned the study’s findings and advised that the analysis was limited and does not truly support the authors’ assertion of conclusive sex differences (Joel & Tarrasch, 2014).

New perspectives in neuroscience research

Across the field of neuroscience, some researchers assert that research has not provided enough evidence to conclude that female and male brains are fundamentally different. These researchers emphasise that inconsistencies in the data make this conclusion unsupportable and that studies investigating sex differences often find many similarities between female and male brains (Joel, 2012; Joel et al., 2015).

Fine (2013) identified three major issues with functional neuroimaging data collected to assess sex differences in the brain. Firstly, Fine notes that some research has cited evidence of sex differences based on a single study, small sample sizes and/or limited analytic techniques. This means that the potential for findings of this research to be generalised to the wider population becomes questionable.

Secondly, while functional neuroimaging studies illustrate the areas of the brain active when completing particular tasks, it is not always true that different brain functioning results in different behaviour. Many studies speculate, or make ‘reverse inferences’, about the mental processes that could result from brain activation. An example of a reverse inference might be that differences in patterns of brain activation between females and males in a particular task must mean that females and males use different mental processes to complete that task. However, Fine notes that mental processes are highly complex and involve interaction between many different regions of the brain. This argument is crucial as it highlights that structural differences in the brain between one individual and another do not necessarily mean that those two individuals will present different behaviours (Dussauge & Kaider, 2012). Fine also highlights that ‘group differences in brain activity are not readily translated into psychological
differences and this gap in knowledge of brain-mind relations creates a danger that, as in the past, gender stereotypes will be drawn upon to putty-fill in the gap’ (Fine, 2013, p. 370).

Fine’s third and last point emphasises the role of plasticity in the structure of the brain and in the mental processes we undertake. Research has demonstrated that the brain is an adaptive organ that changes in relation to environmental factors (Fine, Jordan-Young, Kaiser, & Rippon, 2013; Miller & Halpern, 2014). Fine (2013) suggests that given plasticity is so important for neurodevelopment, it is impossible to conclude whether sex differences found in neuroimaging studies are because of biologically set, ‘universal male/female neural signatures’ (p. 397) or due to the influence of environmental (e.g. cultural) factors on brain development.

More than the sum of the parts

A recent study suggests a shift in perspective is needed in the area of sex differences in neuroscience research. This study examined results of neuroimaging studies with more than 1400 participants and found substantial overlap in the structure of female and male brains (Joel et al., 2015). This research provides a new perspective by investigating the brain as a whole rather than focusing only on a single brain region. The authors concluded:

Our study demonstrates that although there are sex/gender differences in brain structure, brains do not fall into two classes...nor are they aligned on a ‘male brain-female brain’ continuum. Rather, even when considering only the small group of brain features that show the largest sex/gender differences, each brain is a unique mosaic of features... (Joel et al., 2015, p. 5)

The authors propose moving away from research that seeks out sex differences in the brain because these studies do not acknowledge the inherent individual differences in the structure and function of the human brain. This idea is supported by members of the neuroscience field concerned with the ethical implications of research that investigates ‘hardwired’ brain differences between the sexes. For instance, Fine (2012) questions whether evidence of differences between female and male brains could lead to increased endorsement of gender stereotypes, gender roles and gender bias.

Such concerns are particularly relevant to mathematics education where gender differences have been widely studied and explained using ‘biological’ evidence. For instance, a 1985 discussion paper commissioned by the ACT Schools Authority stated that a common myth in the community was that ‘girls, physiologically, are incapable of comprehending and manipulating symbols or of thinking in an abstract way’ (ACT Schools Authority, 1985). Previously it was pointed out that neuroscience research has been used in education to provide a rationale for single-sex education and to validate claims that girls and boys learn differently. However, the research presented here suggests that these statements are misleading and are likely based on the misrepresentation of neuroscience research (Eliot, 2011). This does not mean that single-sex education is not a valuable approach to education, only that basing this approach on neuroscience research is not scientifically valid – evidence that females and males achieve at different levels does not necessarily equate to learning differences.

Evidence that females and males achieve at different levels does not necessarily equate to learning differences.

Given these types of developments and those of the past in education, concern over the ethical implications of neuroscience research into brain differences between the sexes, and the impact of these differences on things like mathematics learning, seems warranted. On the other hand, psychological and educational research can offer some perspectives that may explain the gender differences observed in mathematics and point to opportunities for intervention.
Psychology and education’s perspectives on gender differences in mathematics

Psychological research has a longstanding history of investigating gender differences in learning and achievement, particularly in mathematics. As in neuroscience, some research in psychology in the past attributed male advantage in mathematics and the higher percentage of males engaged with STEM subjects to biological factors that predisposed males to be more proficient at the cognitive processes involved in mathematical learning. (e.g. Baron Cohen, 2002). The current psychological viewpoint does not support the position of a male ‘intrinsic aptitude’ for mathematics, with research suggesting there are no gender differences in children’s cognitive abilities and therefore no difference, on average, in the potential for females and males to achieve in mathematics (Spelke, 2005). Research on the prevalence of dyscalculia, a mathematics-specific learning disorder defined by Devine, Soltész, Nobes, Goswami and Szücs (2013) as the ‘selective impairment of mathematical skills of developmental origin’ (p. 31), corroborates this idea. Dyscalculia is thought to be present in somewhere between 1.3% and 10% of the population. Devine and colleagues found similar rates of dyscalculia in girls and boys in a sample of more than 1000 primary school children. The authors concluded that both genders should be considered equally when investigating mathematical learning difficulties in the classroom.

Motivational beliefs and social factors

Research findings like this have led researchers away from focusing on gender differences in cognitive skills to examining other factors that may contribute to females being less engaged with mathematics (Spelke, 2005). Eccles and colleagues (e.g. Eccles, Adler, & Meece, 1984; Eccles & Wigfield, 2002) proposed that achievement is influenced by socialisation processes via the impact of social factors on students’ interest or value, competence beliefs and emotional engagement with a subject. For example, students’ interest or valuing of mathematics could be influenced by parents and peers. This is a prominent theory in education and psychology and is important when considering the gender gap in mathematics achievement, particularly given the PISA findings discussed earlier that 15-year-old Australian female students report lower levels of intrinsic value, lower levels of self-efficacy and higher levels of mathematics anxiety.

Reviews of psychological research have demonstrated that motivational beliefs – including personal beliefs about the value of mathematics, as well as self-efficacy and competence beliefs – are powerful factors that may account for gender differences in achievement and engagement with mathematics (Newcombe et al., 2009). One study examined the ‘coupling’ of interest (or intrinsic value/how much mathematics is enjoyed), competence beliefs and achievement in mathematics for students to see how these three factors affected one another between Year 1 to Year 12 of school. They found that the three factors were positively related to one another and thus, achievement improvements over time required concurrent increases in students’ level of interest in mathematics and their competency beliefs (Denissen, Zarret, & Eccles, 2007). Research has also demonstrated that mathematics anxiety is associated with poorer mathematics achievement (Carey, Hill, Devine, & Szücs, 2016).

Other core motivational beliefs may contribute to the gender gap in mathematics. For instance, some research has shown that female college students in the United States were more likely to become disengaged with mathematics if they believed that their mathematics ability was predetermined and therefore fixed (Burkley, Parker, Stermer, & Burkley, 2010). Another study found that female college students had a lower sense of belonging in mathematics if they perceived that their college environment encouraged gender stereotypes about mathematics (e.g. females are not as good at calculus as males) and perpetuated the idea of mathematics ability being fixed (Good, Rattan, & Dweck, 2012). Furthermore, perceptions that parents and teachers have about children’s competency in mathematics can be influenced by gender stereotypes and consequently impact on children’s motivation and achievement in mathematics (Gunderson, Ramirez, Levine, & Beilock, 2012).
The impact of stereotypes emphasises the important role that socialisation can play in females’ engagement with mathematics. The theory of stereotype threat in relation to gender and mathematics proposes that when activated, negative stereotypes can affect females and result in lower achievement levels for females versus males (Schmader, Johns, & Forbes, 2008; Shapiro & Williams, 2012). A study in the United States found that female students aged five to seven years old were more likely to underperform in a mathematics test if their mothers endorsed negative gender stereotypes about mathematics (Tomasetto, Alparone, & Cadinu, 2011).

Addressing the gap

Stoet and Geary (2012) proposed that while stereotypes may be a part of the explanation of poor female engagement and achievement in mathematics, other factors are also important and warrant attention, particularly in terms of intervention. One of the factors these researchers point to is spatial processing, which is an area of mathematics that has shown consistent trends of female underperformance (Kucian, Loenneker, Dietrich, Martin, & von Aster, 2005). More recent research suggests that the gender gap could be addressed, as Stoet and Geary suggested, through training. Studies have found that gender differences in performance on spatial processing tasks were significantly reduced after playing a digital game (Feng, Spence, & Pratt, 2007; Yang & Chen, 2010). These findings are significant because they emphasise that gender differences in mathematics are not fixed. The findings also raise questions about whether gender gaps in participation and engagement could also be reduced with targeted intervention. For instance, research showing the impact of training on spatial processing can also be considered in conjunction with evidence that higher levels of mathematics anxiety reported by females may be associated with poorer spatial processing (Maloney, Waechter, Risko, & Fugelsang, 2012). The authors of this study were careful to note that their findings could not confirm a causal relationship between anxiety and spatial processing. Instead they proposed that further investigation was needed to determine whether females may be, in part, more anxious about mathematics because of poor spatial processing skills. Further study could also investigate if the training effects of digital games could extend beyond improvements to females’ performance on spatial processing tasks to also reducing levels of anxiety for females who are fearful of mathematics.

Taken together, this psychological research suggests that learning approaches are not fixed and the potential for growth and change can be seen in an individual’s physical, motivational and achievement profile over time. Unfortunately, there are many examples of work that does not wholly operate within this philosophy. In an article titled, ‘Different, not better: Gender differences in mathematics learning and achievement’, the authors propose

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The findings also raise questions about whether gender gaps in participation and engagement could be reduced with targeted intervention.

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Percentage of Australian 15-year-old students who are high achievers in mathematics, by gender

Source: PISA 2012: How Australia measures up (Thomson, De Bortoli, & Buckley, 2013)
that boys and girls learn differently and provide a list of 10 strategies teachers can use in their classroom to acknowledge these differences (Geist & King, 2008). Some of these, like ‘avoid labelling’, are useful as they suggest challenging gender stereotypes; others, however, are supplemented with statements such as ‘girls tend to be a storehouse of knowledge, while boys are more comfortable at applying knowledge’ (p. 47) or ‘girls tend to prefer cooperative learning activities whereas boys prefer competitive ones’ (p. 48). The article concludes by reminding teachers ‘to support excellence in both boys and girls we must design experiences and curriculum that meet the needs of boys and girls by understanding their uniqueness’ (p. 50). These types of messages sent out to the education community can be dangerous because of their tendency, as Fine (2012) says, to encourage gender bias and pigeonhole students. It may be that female and male students have certain preferences for learning, likely encouraged through various socialisation processes, however, this does not mean that they cannot learn in other and various ways. Furthermore, it is a generalisation to say that all females or all males will have a preference for a particular learning approach or environment. Rather, the message from neuroscience and psychological research is that given new environmental opportunities there is always the potential for change and growth.

Concluding thoughts

Educational research clearly shows gender differences exist in mathematics achievement, participation and engagement. Some might be tempted to use neuroscience to reduce the cause of this to structural or functional differences in the brain and/or psychology to suggest that deficiencies in mental processes or cognitive skills can account for these findings. The underlying assumptions of these explanations could be interpreted as, firstly, that biological or ‘hardwired’ differences between females and males account for these findings and, secondly, that achievement differences are indicative of learning differences – if boys perform better than girls or achieve at higher levels, then they must learn differently (Eliot, 2011). In this paper, we have shown that research does not support this view.

Within the field of neuroscience, evidence of hardwired sex differences in the brain is measured against data that show the brain to be adaptable and influenced by an individual’s environment. Furthermore, the ethical implications of studying sex differences in the brain should be carefully considered given the potential for data on brain-related structural differences to reinforce gender roles or stereotypes. In psychological research, where gender differences in cognitive skills have been found, there has been evidence that some of these differences can be reduced through training. Along with educational research, psychology has also demonstrated that motivational factors, such as value, competence beliefs, sense of belonging and anxiety, have a large impact on mathematical achievement and attitudes towards future learning in mathematics and that female students tend to report more negative motivation towards mathematics.

It was not possible in this paper to examine all research in the area of gender differences and mathematics. For instance, the paper has not touched on neuroscience studies that have investigated different activation patterns between genders in mathematical tasks. However, the intention was to highlight research relevant to the issue from neuroscience, psychology and education. The take-home message seems to be one that is emphasised in neuroscience research; the principles of plasticity apply in relation to neurodevelopment and students’ engagement.

In line with this emphasis on plasticity, the review of evidence presented in this paper suggests that approaches designed to target the gender gap should be multifaceted. Programs that allow struggling female students to practice their mathematical skills could be beneficial, as could initiatives that challenge negative gender stereotypes, beliefs about fixed ability and feelings of anxiety. Furthermore, efforts to increase students’ interest, enjoyment or intrinsic value, improve confidence in students’ perceptions of their competence in mathematics and promote the value of mathematics for future educational and career aspirations could also be positive. The more mathematics is perceived in our society as a subject that is useful, enjoyable and attainable by all, irrespective of gender, the more likely the gender gap will start to close.
References

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Changing Minds: Discussions in neuroscience, psychology and education is an initiative of the Centre for Science of Learning @ ACER (www.acer.edu.au/csl).

ACER is at the forefront of a new transdisciplinary field that we believe has the potential to improve teaching and learning. Research in neuroscience, cognitive, developmental and social psychology, and education are adding to our understanding of fundamental learning processes and of the conditions that lead to successful learning.

Our work allows us to bring current research from those various disciplines together to gain better understandings of the important role of emotions, brain and cognitive development, and learning environments for learning processes, and these insights will have direct implications for teaching and learning in educational settings.

Through applying findings from neuroscience, psychology and education, ACER is developing evidence-based strategies for learning, evaluating existing strategies, and creating a powerful narrative about the role of the brain in learning.