Chapter 13
Gender and Mathematics Education: An Overview

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Abstract Key findings and theoretical trends that have shaped research on gender and mathematics education are described in context. A brief historical note precedes the overview of the foundational work conducted in the 1970s. The assimilationist and deficit models that framed the early intervention programs designed to promote females' participation and learning of mathematics are discussed, as are the subsequent challenges and reassessments provided by broader feminist perspectives. The interactive influence on mathematics learning of relevant personal and contextual variables and the move towards more complex models of equity embedded in broader social justice concerns are highlighted. Given its enabling role in educational and career pursuits, and that gender equity concerns will thus remain a significant item on the research agenda of (mathematics) educators in many countries, guidelines for future work are offered.

Keywords Mathematics · Performance · Participation · Feminist perspectives · Gender · Sex

13.1 Introduction

Historically, males were thought to be more suited than females to studying mathematics and being engaged in related areas. According to Mackinnon (1990): "There are perhaps only three or four women until the nineteenth century who have left behind a name in mathematics. Women were lucky to receive any education at all" (p. 347).

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Reviews of research on gender and mathematics learning typically begin with findings from the 1970s. Yet history should not be ignored. It is useful to refer, briefly, to several females now celebrated or remembered for their mathematical prowess in earlier times.

13.1.1 A Brief Historical Note

Emilie du Châtelet (1706–1749), Maria Agnesi (1718–1799), Sophie Germain (1776–1830), Mary Somerville (1780–1872), and Ada Lovelace (1815–1852) are among those who lived during the eighteenth and nineteenth centuries and whose contributions to mathematics are still considered noteworthy (see for example Lewis 2017; Osen 1974). While the quality and focus of their mathematical endeavours varied, a common thread is evident in accounts of their lives: a firm determination to pursue mathematics, an environment that lauded education, and at pivotal times, constructive support for their work from a critical family member or friend. Mary Somerville, for example, came from a home where the education of sons was considered more important than that of a daughter. In her case an important advisor made a difference: the Scotsman William Wallace, editor of the mathematical journal, the Gentleman's Diary. Early widowhood gave Somerville the financial security to pursue her mathematical studies. Subsequently a supportive second husband enabled her to develop her mathematical interests more intensively (see Patterson 1974 for more information).

Other earlier but more mundane examples of females' successful participation in mathematical pursuits can be gleaned from an English publication, the Ladies' Diary or Women's Almanack, launched in 1704. Three years later the editor began adding mathematical questions to its contents. This strategy continued until the final issue in 1840, when, co-incidentally or not, the Ladies' Diary merged with the above mentioned Gentleman's Diary.

Thanks to the decision by successive editors to reward early and elegant solutions with a copy of the following year's diary, and a listing of the names of those who proposed and answered the questions (Leybourn's Index 1817), confirmation of females' mathematical contributions to the Diary can be traced. Reflecting on the quite remarkable history of this publication, Perl (1979) argued that the "existence of the Ladies' Diary … indicates that stereotypes about the inability of women to understand and enjoy mathematics were less strongly believed in the 18th century than they are today" (p. 36). From careful inspection of the writings of Leybourn (1817), and other sources, it can be inferred that many of the female contributors to the mathematical section of the Ladies Diary' were the wives, daughters or other close relatives of men engaged in mathematical pursuits (see e.g., Costa 2000; Leder 1980; Perl 1979). Decades ago, it appears, given an appropriate milieu and academic and personal support, there were females who were willing and capable of engaging in mathematical pursuits.

13.2 More Recent Times

Research and community interests in gender differences in achievement and participation in mathematics grew rapidly in the 1970s. Recognition of the critical filter role played by mathematics in educational and career options has ensured that stake holders, researchers, practitioners, and policy makers continue to have an interest in this issue.

Key findings and theoretical trends that have shaped research on gender and mathematics education are considered in the remainder of this chapter. Early trends, evidenced in the 1970s, are considered first, followed by brief overviews of dominant trends and developments in successive decades.

13.2.1 The 1970s—The Work Begins

The seminal research of Fennema and her colleagues in the 1970s (e.g., Fennema and Sherman 1976, 1977) can be considered as an important catalyst for substantive and scholarly investigations on gender issues in mathematics education. Evidence of the extensive, and enduring, impact of this work can be inferred from multiple sources. These include Walberg and Haertel's (1992) finding that the Fennema and Sherman (1977) article was among the most commonly cited work in the Social Sciences Citation Index for the period 1966–1988. More recently, in September 2014, it was reported in the Journal for Research in Mathematics Education [JRME] that Fennema and Sherman's (1976) article had been its most frequently accessed article over the previous three years.[1] More broadly, Lubienski and Bowen (2000) examined 48 major educational research journals accessible on the ERIC data base and published between 1982 and 1998, and found that, of the equity groupings used to categorize the content of relevant articles, gender and mathematics issues received the most attention.

From the mid 1970s onwards, the documentation of gender differences in participation and performance in mathematics, and explorations of apparent positive and negative contributing factors, were important foci of those concerned with gender and mathematics. Factors likely to be implicated were identified, and intervention strategies were initiated and evaluated. As summarised by Fennema (1974), sex differences in boys' and girls' mathematics achievement were rarely found before or in the early grades of elementary school. In the upper elementary and early high school grades differences were sometimes reported. When significant differences were found they tended to be in the boys' favour on higher-level cognitive tasks but in the girls' favour when lower-level cognitive tasks were being measured. "Is there 'sexism' in mathematics education?" Fennema (1974) asked

[1]Information retrieved September 2014 from http://www.jstor.org.ezproxy.lib.monash.edu.au/action/showMostAccessedArticles?journalCode=jresematheduc.

rhetorically. “If mathematics educators believe that there is a sex difference in learning mathematics … and have not attempted to help girls achieve at a similar level to boys, then this question must be answered in the affirmative” (p. 137).

Assumptions that gender differences in mathematics learning were, at least in part, the result of social structures, inadequate educational opportunities, and biased instructional methods and materials shaped much of the work undertaken. Traditional quantitative research methods usually informed the experimental work devised. The removal of school and curriculum barriers, and possibly the resocialization of females, were assumed to serve as fruitful pathways for achieving gender equity. Male (white and Western) norms of performance, standards, participation levels, and methods of work were typically accepted uncritically as the optimum goal for all students. If these were not attained, females were considered deficient, or to use a theme from Kaiser and Rogers (1985), they were perceived as a problem in mathematics, and were to be encouraged and helped to assimilate. This notion, of supporting females to reach standards and achievement equivalent to those of males, was consistent with the tenets of liberal feminism.

13.2.2 A Terminological Interlude

The mix of the terms “sex differences” and “gender differences” in the above paragraphs is not fortuitous. In early work, researchers invariably used the term sex differences when referring to differences in mathematics performance or participation between males and females. In recognition that such differences were not necessarily biologically based, the term gender began to be used as an indicator that differences found were unlikely to be attributable to biology alone. Increasingly the use of gender, rather than sex, differences in mathematics began to appear in scholarly publications. Not all agreed with this putative distinction.

> Experts and lay people alike are well aware that the words they use reflect and shape how we think. What words should we use when discussing differences in achievement tests scores for boys and girls? Those who advocate the use of “gender” for differences that are psychosocial in origin and “sex” for differences that are biological in origin are implicitly assuming that these are two separable influences, an approach that is consistent with behavioural genetics which assigns separate numerical estimates to each type of influence. (Halpern 2002, p. 89)

The sex/gender conceptual distinction, and attendant terminology, has continued to attract attention, more frequently beyond rather than within mathematics education. Reflecting on years of research in studies in education and in psychology, Damarin (2008) concluded:

> the psychological literature on women, gender, and mathematics has two distinct strands, the first continuing a tradition of probing and documenting sex-based differences in various aspects of mathematical performance and the second investigating how knowledge of group differences affects judgment and thus experience of individuals. (p. 108)

This distinction is reflected in documents published under the auspices of the American Psychological Association [APA], including the *APA Dictionary of Psychology* (2015a). There gender and sex are respectively defined as follows:

> Gender (n): the condition of being male, female, or neuter. In a human context, the distinction between gender and SEX reflects the usage of these terms: Sex usually refers to the biological aspects of maleness or femaleness, whereas gender implies the psychological, behavioral, social, and cultural aspects of being male or female (i.e., masculinity or femininity). (APA 2015b, p. 2)

and

> Sex (n): the traits that distinguish between males and females. Sex refers especially to physical and biological traits, whereas GENDER refers especially to social or cultural traits, *although the distinction between the two terms is not regularly observed*. (APA 2015b, pp. 5–6, emphasis added)

The binary construction of sexuality is itself progressively being examined and found wanting is some quarters, inside and beyond the educational research community. Notably, beginning in 2017 the American Educational Research Association [AERA] has been collecting demographic data from its membership via a more extensive range of sex and gender self-identifiers:

> Which best describes your gender identity?
>
> Female/Woman
>
> Male/Man
>
> Transgender Female/Transgender Woman
>
> Transgender Male/Transgender Man
>
> Another gender identity (please specify): ____________________ (AERA 2018)

How, or whether, such new categorizations will impinge on future research in gender/sex differences in mathematics learning remains to be seen.

13.3 The 1980s—The Field Matures and Diversifies

Throughout the 1980s assimilationist and deficit model approaches continued to mould and underpin many of the intervention initiatives aimed at achieving gender equity in mathematics learning outcomes. Data on males' and females' participation and performance in mathematics subjects and tests continued to be reported in scholarly publications. Attempts to identify underlying sources and causes often accompanied such reports. Personal and environmental factors as well as previously unchallenged government policies began to be examined. Researchers concerned with gender differences and mathematics learning were acknowledged as significant contributors to the broader field of research on affect and mathematics learning.

As argued by McLeod (1992), the "important area of research on beliefs comes mainly out of the work on gender differences in mathematics education" (p. 580).

Undoubtedly influenced by work developed in the broader research community, new and searching issues were raised. The themes fuelled by the work of Gilligan (1982) and Belenky et al. (1986), as well as other feminist critiques of the sciences and of the Western notions of knowledge proved particularly powerful. Provocative questions, which also served as pointers to new research directions, began to be raised more forcefully. No longer was it uncritically accepted that subjects such as mathematics and science should be taught, valued, and assessed in ways that seemingly favoured males. No longer was it simply assumed that learning styles, materials and conditions that advantaged males should uniquely be supported. That young women should strive to emulate males' ambitions, goals, and values was no longer taken for granted. These perspectives intensified during the 1980s and served as powerful catalysts for attempts to make the curriculum and instructional strategies less alienating for females.

To summarise, the more critical attempts to question earlier and historically accepted explanations for gender differences in mathematics learning began to affect the framing and delivery of interventions aimed at combating inequities. Efforts were made not only to make females more central to mathematics but also to review and expand the curriculum to incorporate the needs and interests of a broader range of students. More broadly, Leder (2001) reflected:

> The assumptions of liberal feminism that discrimination and inequalities faced by females were the result of social practices and outdated laws were no longer deemed sufficient or necessary explanations. Instead, emphasis began to be placed on the pervasive power structures imposed by males for males.… Some researchers…wished to settle for nothing less than making fundamental changes to society. Advocates of this approach, often classed as radical feminists, considered that the long-term impact of traditional power relations between men and women could only be redressed through such means. (vol.1, p. 48)

The assumptions embedded in the "women as central to mathematics" phase were not without their dangers. The focus of some intervention programs on women with exceptional and rare mathematical talents ultimately proved problematic. Some of the portrayals, it seemed, simply confirmed how difficult it was for an "ordinary" (female) student to become an "extraordinary" mathematician. Reinforced were the hardships that needed to be endured, the challenges to be overcome, and the price to be paid by females for success in mathematics. Programs which valued and nourished qualities and characteristics presumed to be exclusively or primarily female might give the impression, directly or indirectly, that such qualities were essential to females. That females who did not possess or aim for them might feel excluded and devalued was unintended and a consequence to be avoided. The essentialism inherent in some programs risked perpetuating traditional gender stereotypes rather than redressing gender inequities. Nevertheless, there was widespread recognition that previously unchallenged assumptions, traditions, and cultural exclusivity needed to be examined and possibly redefined. Snyder's (2008) claim that responses "to the 'category of women' debates of the late 1980s and early 1990s, that began with a critique of the second wave contention that women share something in common as woman: a common gender identity and set of experiences" (p. 183), captured the thrust of yet another phase, variously addressed in the literature and often labelled as the third wave of feminism.

The meta-analysis published by Hyde et al. (1990) serves as one useful indicator of performance statistics on gender differences in mathematics recorded by the end of the 1980s. Their sample comprised 100 studies of gender differences in mathematics performance. These studies were published between 1963 and 1988, yielded 254 independent effect sizes, and collectively represented test data of more than three million students. Core information on which their data were based and basic conclusions they drew can be summarised as follows:

- Gender differences in mathematics performance in samples of the general population were negligible (d = –0.05) and favoured females; averaged over all studies the difference in mathematics performance was a little larger but still small (d = 0.20) and in favour of males.
- Girls did slightly better than boys in computation.
- In elementary and middle school there were no gender differences in problem solving, but in high school and in college, differences on this component favoured males.
- Gender differences in favour of males "grew larger with increasingly selective samples and were largest for highly selected samples and samples of highly precocious persons" (Hyde et al. 1990, p. 139).
- The effect size of the gender difference declined over the years – from d = 0.31 for studies published in or before 1973 to d = 0.14 for studies in or after 1974.

Pointing to the different performance patterns, the authors argued that general statements about gender differences in mathematics performance masked the complexity of the performance pattern and could thus be misleading. Furthermore, "where gender differences do exist, they are in critical areas" (Hyde et al. 1990, p. 151). Schools, they further argued, should implement programs and procedures to improve the teaching of mathematics, "such as internalized belief systems about mathematics, external factors such as sex discrimination in education and in employment … and the mathematics curriculum at the pre-college level" (p. 151).

A detailed overview of intervention programs developed and produced in the 1980s is clearly beyond the scope of this chapter. Fennema et al. (1980) intervention compendium, with its reprints of (then) relevant research articles, as well as detailed materials for student, teacher, counsellor, and parent workshops still serves as an informative source some 40 years after its publication. Many of the programs developed and adopted in the 1980s and beyond can be traced to this comprehensive resource, although this is typically unacknowledged.

It seems judicious to conclude this section with a quote from Leder et al. (1996, p. 966) with which they began their overview of intervention programs as follows:

On December 6, 1989,

At the Ecole polytechnique de Montréal,

A young man entered an engineering classroom.
He ordered women to stand on one side,
men on the other side.
He shot the women.
Then he walked through the school
and shot some other women.

"In this tragic incident", they added, "13 female students and one female staff member were killed. The perpetrator believed that women had usurped his rightful place in engineering and in society" (Leder et al. 1996, pp. 966 and 979). The massacre, it became known, was the shooter's lone fight against feminism and what he regarded as women unfairly taking up positions in traditionally male fields.

13.4 The 1990s—Consolidation and New Directions

Reviews of research about mathematics and gender published in the first half of the 1990s (e.g., Leder 1992; Fennema and Hart 1994) indicated that the trends in performance differences in mathematics between males and females reported two decades earlier were still apparent. Possible explanations for these persistent findings shadowed those considered in earlier research and comprised both environmental variables, including school-, teacher-, peer group-, and parent-related variables, as well as the impact of the wider society. The influence of learner-related cognitive variables and internal belief variables also continued to attract considerable research activity. When gender differences were found, Leder (1992) concluded, they are typically small compared to the much larger within-group variations. "Collectively the body of research available to date suggests that there are small, subtle, interactive, and cumulative links between gender differences in selected internal belief variables and gender differences in mathematics learning" (p. 616). Implied in this summary is a warning against conducting research, or interpreting its findings, with a simplistic focus on the impact of gender per se, without a recognition of the interactive influence of relevant personal and contextual variables.

According to Fennema and Hart (1994), while feminist perspectives were increasingly recognized by those working outside mathematics education, research on mathematics and gender, as gleaned from the contents of JRME, had remained largely untouched by this broader body of work. At the same time they argued presciently, "we think that feminist perspectives can contribute to mathematics education research in the kind of research questions that are explored, whose questions are asked, whose voices are heard, and the research methods employed" (p. 653). Looking at the wider field of mathematics education research reported beyond JRME, Leder et al. (1996) noted "the growing feminist literature on the gendering of mathematics" (p. 945) that added to the pool of work embedded within the traditional research paradigms.

Throughout the 1990s different theoretical models were invoked to support mathematics and gender focussed research. The interactions between gender, learner-related, and contextual variables such as socio-economic status, cultural and ethnic affiliations, continued to be explored, not only using the more traditional quantitative approaches but increasingly also drawing on alternate methodologies that foregrounded social constructivist perspectives. A considerable body of work at that time drew, directly or indirectly, on the expectancy-value theory of achievement motivation and often also on the model of academic choice. This has continued until the present. The model of academic choice was expounded in some detail in the early 1980s by Eccles et al. (1983). Factors likely to enhance, or reduce, students' performance in mathematics and continued engagement with the subject were examined. At the same time, different research paradigms were considered. Damarin's (2000) evocative explanation why some students choose options other than mathematics is worth noting:

> Mathematics teachers and researchers have observed that mathematics is unique among school subjects in that, for many students, failure in mathematics is not an occasion of embarrassment; these students (often with the support of parents, peers, and sometimes guidance counselors and other teachers) refer to the inability to do mathematics with a certain pride. Thus, from leading journals of public intellectual discussion, from the analyses of sociologists of science, from the work of (genetic) scientists themselves, from the pages of daily papers, and from practices of students and adults within the walls of our schools, there emerges and coalesces a discourse of mathematics ability as marking a form of deviance and the mathematically able as a category marked by the signs of this deviance. (p. 78)

Given the reality of the social climate in which they functioned, Damarin among others drawing on sociological perspectives, emphasized that it could not simply be assumed that all students, whether male or female, would necessarily aim for intensive study or proficiency in mathematics and feel diminished if they focussed their attention and efforts elsewhere.

Increasingly, a subtle but gradual shift in the focus on equity broadened. Social justice issues became more prominent. New avenues for research in mathematics education were generated by concerns raised about disadvantages, in the home and in the labour force, faced by females from a working class background, from certain ethnic groups, or those whose dominant language differed from that spoken in their country of residence. To quote Burton (2003), "since earlier publications on gender and mathematics education … there has been a shift in focus on equity to a more inclusive perspective that embraces social justice as a contested area in mathematics education" (p. xv). For many researchers the term equity could no longer simplistically be considered a virtual synonym for gender; gender was more constructively linked to, or within, a complex set of variables. More complex research designs and varied research methods were needed, with advocates of a social constructionist approach often placing strong reliance on qualitative methods. By the early years of the 21st century, Gutiérrez (2013) argued: “Sociocultural theories, once seen as on the fringe of a mainly cognitive field, now take their place squarely within mainstream mathematics education journals” (p. 38).

13.5 Contemporary Times: The 21st Century

Drawing on 25 years of research on gender and mathematics education Leder (2001) wrote:

> Gender equity concerns have represented a significant item on the research agenda of (mathematics) educators in many countries - in highly technological societies as well as developing nations. International comparisons, formal and informal, have highlighted the roles of class and culture. For a given society, the status of mathematics in the lives of females is invariably linked to their status in that society. Male norms, and acceptance of difference without value judgments, have been more likely to be challenged in countries with active and long standing concerns about equity issues. Collectively, the body of work on gender and mathematics education reflects an increasing diversity in the inquiry methods used to examine and unpack critical factors. More radical feminist perspectives are being adopted, females are less frequently considered as a homogeneous group, and scholarly evaluations of interventions are becoming more prevalent (vol. 1, pp. 48–49).

As expected, themes and directions tracked in previous decades have also dominated in more recent research. Gender is often included among the variables whose impact on learning mathematics is being explored, but now frequently not to the exclusion of other moderators. As noted by Morgan (2014), within the field of mathematics education, too, many are seeking “to go beyond a focus only on conventional educational outcomes as indicators of success or failure, seeing identity, social recognition and participation as equally important dimensions of social justice” (p. 124).

In their account of the rich and ongoing journey leading from Mathematics and Education to Mathematics Education, Furinghetti et al. (2013) pointed to the variety of research perspectives, fields as diverse as psychology, sociology, cultural studies, and political studies, on which researchers have drawn to explore issues in mathematics education. The different lenses used by those adding to research on mathematics and gender make summarising the ongoing pool of studies a daunting task. Careful scrutiny is needed to decide whether a researcher’s personal beliefs and theoretical orientation might have influenced, directly or indirectly, the scope of the study undertaken, the modes of data gathering used, and the interpretation of the findings obtained.

Now, more than four decades since gender differences in mathematics performance were highlighted and spawned intensive and extensive investigations, are gender differences in mathematics achievement still being reported? Data pertaining to achievement data are examined first. Inevitably only a small sample from the large pool of relevant information is cited.

13.5.1 Achievement

According to the Organisation for Economic Co-operation and Development [OECD] (2009) there are at least three core reasons for studying gender differences in mathematics achievement: "(i) to understand the source of any inequalities; (ii) to improve average performance; and (iii) to improve our understanding of how students learn" (p. 8).

The meta-analysis reported by Lindberg et al. (2010) not only contains useful summative data but also serves as a ready comparison with the work published 20 years earlier (Hyde et al. 1990) and referred to earlier in the chapter. The sample in the Lindberg et al. (2010) meta-analysis comprised 242 studies of gender differences in mathematics performance. These studies were published between 1990 and 2007 and represented test data of 1,286,350 people. Collectively their data revealed the following:

- The gender difference weighted over all studies was small (d = 0.05).
- Examination of data by problem type and content, by sample characteristics including ability, nationality, ethnicity, and age yielded few statistically significant differences in performance, with selectivity (in terms of achievement level) and age being the exception.
- In high school, small gender differences in complex problem solving were found in favour of boys.
- There was no apparent trend over time, between 1990 and 2007, of a decrease in any gender differences reported.

Overall, Lindberg et al. (2010) concluded that their data "provide strong evidence of gender similarities in mathematics performance … the existence and magnitude of gender differences in performance varies as a function of many factors … gender can be conceptualized as one of many predictors of mathematics performance" (p. 1133). Socioeconomic status, parents' occupation, and the quality of schooling were among other variables likely to influence performance outcomes.

Although the existence and extent of gender differences in mathematics learning remains a contested issue, the persistence of small gender differences in favour of males continues to be reported in data derived from large scale studies. For example, Else-Quest et al. (2010) used a meta-analysis of the Programme for International Student Assessment [PISA] and Trends in International Mathematics and Science Study [TIMSS] data to examine the occurrence of gender differences in mathematics performance on these large scale international tests. They invoked the gender stratification hypothesis (that is, societal stratification and inequality of opportunity based on gender) as an explanation for the continuing gender gap in mathematics achievement reported in some, but not in other, countries. They concluded that cross-national variability found in the gender gap "can be explained by important national characteristics reflecting the status and welfare of women … (and) the magnitude of gender differences in math also depends, in part, upon the quality of the assessment of mathematics achievement" (Else-Quest et al. 2010,

p. 125). Perhaps a caveat should be introduced here. While useful for reviewing a large body of literature focussed on a common concern, the acknowledged preference for publication of studies with statistically significant findings may bias the outcome of a meta-analysis.

Given the emphasis on large scale data as a resource for the identification, or rejection, of gender differences in performance it is useful to inspect these data in more detail. Leder and Forgasz (2018) are not alone in illustrating how the content of a test or task can influence apparent gender differences in performance. Considering group data for TIMSS 2015 they pointed to provocative nuanced differences which emerge when the data are reported by content domain. At the grade 4 level, boys performed better than girls on *number* items in 21 countries (see Martin et al. 2016) while the mean score for girls was higher than for boys in seven countries. For *geometric shapes and measures*, the mean score for boys was higher than for girls in 14 countries but higher for girls than for boys in nine countries. For *data display*, girls outperformed boys in 13 countries, and boys did better than girls in two countries. Inconsistencies in gender differences in performance by content domain were also found for students in eighth grade. No mean difference in the performance of girls and boys was found in 26 of the 39 countries in which the eighth grade mathematics survey was administered. The mean score for girls was higher in seven countries, and higher for boys in six countries. In *number*, on average, boys did better than girls in 17 countries, while girls did better than boys in four countries. In contrast, on *algebra* domain items, girls did better than boys in 21 countries, and boys did not outperform girls in any countries. Girls also did better than boys on *geometry* items in eight countries compared with two countries where boys outperformed girls on items in this domain. For *data and chance*, boys outperformed girls in six countries, and girls outperformed boys in seven countries.

Group findings for PISA also show an interesting pattern. Again a nuanced appraisal of mathematics assessment data provides constructive insights. In OECD (2014), data are presented *inter alia* in terms of the four content subscales: *change and relationships*, *space and shape*, *quantity*, and *uncertainty and data*. Mean differences in the scores of boys and girls across the OECD countries, it was reported, ranged from 15 points in favour of boys on the *space and shape* scale to a difference of nine points in favour of males on the *uncertainty and data* subscale. Within country group differences varied considerably, however. In the *quantity* subscale, for example, differences ranged from 31 points in favour of boys to 19 points in favour of girls. Such varying patterns of gender differences across the performance of large groups of students on the different scales "highlight the difficulties in designing educational policies that promote gender equity" (OECD 2009, p. 22).

Large scale surveys such as PISA and TIMSS undeniably provide much contextual and moderating information beyond (mean) students' scores on test items. This includes information about the students' home, school, and broader learning environment and measures of students' attitudes, beliefs, and longer term aspirations. Yet, as noted by Leder and Forgasz (2018), carefully contextualized presentations of the vast sets of data generated by these large surveys are often simplified in discussions of national and international performance data. External influences, local expertise, and individual teacher or pupil preferences, participants' social class and the accompanying associated advantages or disadvantages may influence test results. These factors are often minimized or ignored when the outcomes of tests are reported or interpreted by stakeholders or in the popular media. Group differences in mathematics achievement may be simplistically attributed to gender rather than a combination of factors, some more influential than gender per se. Perhaps, not coincidentally, in their exploration in nine countries of the general public's views about mathematics Forgasz et al. (2014) reported that many of the respondents, whose views were sought through advertising on the popular media site *Facebook,* indicated that they believed that studying mathematics was important for all students, irrespective of their gender. However, among those who held gender-stereotyped views, more considered that boys were better than girls at mathematics, science, and computing and that being a scientist or working with computers was more suitable for males than for females. Perceptions that mathematics is a male domain seemingly linger and persist among sections of the general public. According to Hill et al. (2010), some of those who explicitly reject agreement with gender and mathematics and science stereotypes might nevertheless hold such beliefs at an unconscious level. Fictional depictions of school mathematics in books aimed at young adults may further perpetuate rather than challenge gender bias (Darragh 2018).

In contrast to the test measures considered in some detail so far, Voyer and Voyer (2014) compared males' and females' academic performance using the measure of teacher-assigned marks. Their analysis drew on 369 samples yielding 502 effect sizes. For the overall sample of effect sizes, females were found to have a small but significant advantage. Course content, nationality, racial and gender composition, but not year of publication, were significant moderators of effect sizes. The largest effects were in language courses; the smallest in mathematics and science courses. The study by Voyer and Voyer (2014) is another challenging reminder that how achievement is measured can influence apparent gender differences in performance.

In summary: after four decades of consistent, persistent, and often insightful research on gender and mathematics there seems to be at best limited consensus on the size and direction of gender differences in mathematics performance. Might the tendency for statistically significant results to be accepted for publication while non-significant findings are rejected (as discussed by, e.g., Howard et al. 2009) perhaps influence this summation? That there is great variation in the explanations put forward to account for any gender differences found is widely acknowledged.

13.5.2 Participation

Mathematics is considered to be a critical component of the school curriculum, an enabling discipline for STEM-based studies [science, mathematics, engineering and technology], and an important gateway to adult life and occupational opportunities: "Being able to read, understand and respond appropriately to numerical and mathematical information are skills that are essential for full social and economic participation" (OECD 2013, p. 98). Much is written in policy documents and more broadly about the need for the population at large to be equipped with adequate quantitative skills. "There is a global perception that a workforce with a substantial proportion educated in Mathematics, Engineering and Science (MES) is essential to future prosperity" (Marginson et al. 2013, p. 6). At the same time concerns are expressed that the pool of students intending to continue with mathematical studies once they are no longer compulsory appears to be stable or, in the most advanced mathematics courses, to be decreasing (AMSI 2017). Not surprisingly, there are between-country differences in the proportions of students studying non-compulsory mathematics courses at the secondary and tertiary levels (Van Langen and Dekkers 2005), though differences in educational program structures make it difficult to quantify these precisely.

As indicated at the beginning of the chapter, research conducted in the 1970s was partly driven by data on gender differences in participation in post compulsory mathematics courses. Lower female participation in higher level mathematics courses internationally was publicized by early researchers (including, for example, Schildkamp-Kündiger 1982) and continues to be documented (AMSI 2017; OECD 2009; Leder 2015; Lubienski and Ganley 2017; Reilly et al. 2017; Stoet and Geary 2018; Wang and Degol 2017; Wilson and Mack 2014). Particularly disturbing is the trend for females to be under-represented in school level enrolments in the most challenging mathematics subjects and, at tertiary level, the relatively small numbers enrolled in masters and Ph.D. courses. In Australia, for example, the number of masters and Ph.D. graduates has increased slightly, largely due to an increase in number of female graduates. Nevertheless, male graduates at this level still outnumber female graduates three to one (AMSI 2017). As well, females remain in the minority in Engineering and other STEM-related fields (e.g., AMSI 2017; Hill et al. 2010; OECD 2006). Stoet and Geary (2018) maintain that the number of females who continue with, and graduate in STEM studies falls well short of the number that could take that path: "there is a loss of female STEM capacity between secondary and tertiary education" (p. 590).

Over the years, a range of strategies to encourage students to persist with mathematics studies has been advocated. These include, but are certainly not limited to, the following: improving problem solving strategies, curriculum adjustments, single-sex classes, and better pre- and in-service preparation for teachers. That such programs may be particularly beneficial to females is often added strategically. Approaches advocated or adopted in different countries to improve the participation and achievement of students in mathematics and science are variously described at some length, for example, in reports by Marginson et al. (2013) and UNESCO (2017). A promising current, comprehensive Australian initiative, CHOOSEMATHS which is aimed at increasing the participation in mathematics of all students and especially for girls and young women, is certainly worth noting. Importantly not only students and teachers, but also parents are targeted through different aspects of the program. The scope of the longitudinal project is described as follows:

> Since 2015 we have been leading the national implementation of key classroom and pipeline strategies to transform Australia's mathematical capability. With maths essential to a growing number of jobs, it is critical we foster understanding of the value and impact of maths and equip students to embrace these opportunities now and into the future. Working across four key components, the project is addressing pipeline challenges through Schools Outreach, Careers Awareness, CHOOSEMATHS Awards and the Women in Maths Network. (ChooseMaths n.d.).

Many of the perspectives and (inevitably) theoretical and value-driven programs and interventions invoked to explain or combat persistent patterns in gender differences in participation in mathematics and related areas mirror those directed at performance differences. The models proposed typically contain a range of interacting factors, both intra-personal and environmental. Included among the latter are the school culture, social mores, and the values and expectations of peers, parents, and teachers. A contemporary snapshot of workplace environments based on American data is disconcerting. Information, gathered from adults, aged 18 years and over, and who were working in STEM related areas and careers was inspected by gender, race, and ethnicity. Focussing on gender, Funk and Parker (2018) reported as follows:

> … the workplace is a different, sometimes more hostile environment than the one their male coworkers experience. Discrimination and sexual harassment are seen as more frequent, and gender is perceived as more of an impediment than an advantage to career success. Three groups of women in STEM jobs stand out as more likely to see workplace inequities: women employed in STEM settings where men outnumber women, women working in computer jobs, … and women in STEM who hold postgraduate degrees. (p. 6)

They further noted that diversity in the STEM workforce varied quite dramatically and depended on the type and level of occupation. The pervasiveness of females' lower participation than males' in mathematics and other STEM subjects at different levels of education, and acknowledged contributing factors, are also revisited and reviewed in the UNESCO (2017) report.

In summary: As mentioned earlier, gender differences in participation in mathematics in favour of males emerge when the studying of mathematics is optional, and are more pronounced in advanced mathematics subjects. The imbalance increases at higher levels of education and is also evident in gender differences in participation in STEM fields, and again particularly at the more advanced career levels.

13.6 Future Directions

National policies for promoting STEM, it is often claimed, are "generally conceived in human capital terms. Emphasis on the 'pipeline' of school and tertiary STEM education is frequently motivated by issues concerning the STEM labour force argued instrumental to economic growth and well being" (Marginson et al. 2013, p. 94). To this is added the need to address "the gender challenge, … a deepening issue across all STEM disciplines, (which) is critical to ensure skill supply can meet industry need into the future" (AMSI 2017, p. 6). Given these assumed priorities, taken from Australian publications but also voiced elsewhere, and the ambivalent and at times contradictory findings reported to date and reflected in this chapter, work on gender and education will continue to be an important part of the research agenda in mathematics education. From the material presented so far it is clear that relevant data and research on gender and mathematics were gleaned from a staggering range of sources embedded in a variety of disciplines (many indirectly rather than directly linked to mathematics education), and interrogated using multiple methods and procedures. What research is worth doing and reporting? Where should new research efforts be directed to ensure that the field will continue to advance and develop? According to Howard et al. (2009):

> Scientific progress is made by trusting the bulk of current knowledge in the form of implicit assumptions in our research efforts. For example, we trust that … subjects will truthfully report their behavior, and that the theoretical variables of interest are reflected in the specific operational definitions employed. … The corpus of scientific knowledge changes and improves as new evidence supports or alters our beliefs. (p. 117)

Replications and small extensions of earlier work have featured heavily in the annals of educational research and, undoubtedly, will continue to play an important role in future research on gender and mathematics. Replication studies fall into one of two categories: an exact replication of an original study or research involving conceptual replication, for example by exploring from a different perspective the contexts in which the original results were obtained (Cai et al. 2018). Given the unpredictability of human behaviour, the difficulty of random assignment of "treatments" or experiences, and the limitations imposed by practical constraints, exact replication of a previous study is extremely difficult, if not impossible. What criteria should underpin the conduct and reporting of new research? What about studies in which no statistically significant findings are found? When should journal editors be encouraged to publish these? Recently Star (2018) provided a number of benchmarks in the context of replication studies. With some adjustment these requirements clearly have relevance more widely:

> An outstanding replication study article: 1. Makes a convincing case that the study topic of the replication is of great importance to the field, 2. Makes a convincing case that the field will learn something significant from the replication that is not already known, and 3. Convincingly shows that there is reason to believe that the results of the original study may be flawed. (p. 99)

Adhering to the core issues embedded in these principles in planning and executing new research could yield the productive and constructive new insights needed to achieve equitable outcomes in mathematics education for all.

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