

Katherine M. Robinson · Helena P. Osana ·
Donna Kotsopoulos *Editors*

Mathematical Learning and Cognition in Early Childhood

Integrating Interdisciplinary Research
into Practice

 Springer

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ISBN 978-3-030-12894-4 ISBN 978-3-030-12895-1 (eBook)
<https://doi.org/10.1007/978-3-030-12895-1>

Library of Congress Control Number: 2019934797

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Foreword

Over a decade ago, a group of researchers set out to identify the factors in early childhood development that are key predictors of school readiness (Duncan et al., 2007). By combining data from existing, large-scale, longitudinal data sets, they were able to estimate how strongly early math, early reading, early attention, and early social skills predicted later academic achievements. What came as a surprise to many at the time, and resulted in a significant public attention, was their finding that early math skills were not only a stronger predictor of later math skills, but also a robust predictor of children's later reading. Furthermore, Duncan et al.'s meta-analysis of all the reported relationships between early competencies and later skills revealed that overall, early math was the strongest predictor of later academic performance. These findings had a huge impact on the field because they brought into sharp focus the importance of early math skills and provoked greater attention to the study of how children learn mathematics from an early age. Furthermore, these results also lead to a greater level of interest in how to use evidence from research coming from a diversity of fields, including cognitive psychology, educational psychology, cognitive science, and cognitive neuroscience, to design evidence-based programs that foster mathematical skills and understanding in young children.

In the 11 years that have passed since Duncan et al.'s seminal finding, many researchers with different theoretical and methodological backgrounds have focused their efforts to better characterize the mathematical minds of young children. Doing so has led to the development of approaches for the assessment and characterization of children's early understanding of mathematics and the use of resulting knowledge to find ways to optimally foster children's mathematical skills and understanding to set them on a trajectory of learning and growth (Bailey et al., 2017).

Now is an optimal time to take stock of what fruits this period of research and application of research has brought to bear. We have additionally obtained a better understanding of the questions that remain unanswered, the novel avenues that have emerged for research and mathematics education, and the directions that should be the focus going forward. The present edited volume entitled "Early Mathematical Minds" does exactly this and more. The present volume is edited by three esteemed scholars of child development and mathematics education: Katherine M. Robinson,

Helena P. Osana, and Donna Kotsopoulos. These editors have brought together a well-regarded group of scholars who have contributed chapters that represent an accessible, rich, diverse, and interdisciplinary synthesis of what we currently know about the mathematical minds of young children. This volume is a must-read for those seeking a broad overview of recent advances in our understanding of what factors contribute to the successful development of young mathematical minds and how to best foster early math skills and understanding. The contributions are written in accessible language and thus are suitable for a multidisciplinary readership, ranging from educators and educational policy makers to undergraduate and graduate students as well as researchers studying the emergence of mathematical minds.

The contributions within this volume are reflective of the breadth and complexity of research on young children's mathematical minds. By addressing such topics as spatial thinking, computational thinking, the relationship between proportional reasoning and fractions, and spatial and mathematical language spoken in the home environment, the present volume sets itself apart from related books by going beyond a sole focus on factors that influence the development of mathematical minds. The collection offers perspectives on what constitutes effective ways of screening young children's mathematical skills and deeper understandings of how best to intervene in early development in diverse educational settings, including language immersion classrooms. Furthermore, the contributions cover important and widely debated subjects such as the role of gender in mathematics, the role played by manipulatives in early math education, and the potential of technology as a support for early math learning, both in the classroom and in the home environment. By integrating contributions that focus on the latest insights from empirical research into how children develop mathematical minds with explorations of how to best foster this development, the present volume successfully traverses the bridge between basic research on children's early development of mathematical skills, on the one hand, and understanding the application of that research to create both formal and informal learning environments to optimally support and engage young mathematical minds on the other.

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Part I
Infancy and Preschool

Early Mathematical Minds: Interdisciplinary Perspectives on Early Mathematical Learning and Cognition



Donna Kotsopoulos, Katherine M. Robinson and Helena P. Osana

Supporting the mathematical development and learning of children is complex and involves multiple stakeholder groups including parents, caregivers, early childhood educators, teachers, researchers, and policymakers. Adding to the complexity is the reality that diverse research disciplines inform conversations about children's mathematical understanding and learning. Research informing mathematical cognition and learning stems from numerous disciplines and different methodological and theoretical traditions, including education, psychology, educational psychology, cognitive science, mathematics, and neuroscience. These diverse research traditions are often constructed for different audiences, for different purposes, and independently of one another, often resulting in siloed research.

It is our view that research, methods, and theories from different disciplines can complement each other to advance children's mathematics learning. An interdisciplinary approach may result in the creation and validation of approaches that are best suited to support the learning of mathematics, perhaps more so than research typically aligned with traditional psychological methods and theories (Popescu, 2014). Popescu (2014) proposed that it becomes difficult to capture the phenomena under investigation when researchers do not collaborate or communicate fully. It could be argued that educational psychology rests at the intersection between psychology (including its broad range of subfields) and education, and as such, can serve as a vehicle for such interdisciplinary collaboration.

There is also the enduring divide between research and practice (Farley-Ripple, May, Karpyn, & Tilley, 2018; Penuel, Allen, Coburn, & Farrell, 2015). Farley-Ripple

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K. M. Robinson et al. (eds.), *Mathematical Learning and Cognition in Early Childhood*,
https://doi.org/10.1007/978-3-030-12895-1_1

and colleagues (2018) described the problem as a “bidirectional problem in which characteristics of both the research and practice communities must be understood and addressed to strengthen ties between research and practice in education” (p. 235). While numerous hypotheses have been proposed to explain the lack of uptake of research evidence in the practices of parents, early childhood educators, and teachers (Lysenko, Abrami, Bernard, Dagenais, & Janosz, 2014), little consideration has been given to the role the disciplinary tenets within silos have had on the chasm between research and practice.

Educational psychology has evolved over the last 50 years. The original tenets of educational psychology were based on cognitive psychology (Derry, 1992; Mayer, 1993). Although much of the field still has its roots there, the field itself has become more situated in nature and directed toward the lives and experiences of individuals in school settings (e.g., discourse processes in mathematics classrooms, teachers’ day-to-day practices, students’ interpretations of mathematical representations). The degree of application may differ from one study to another, but many educational psychologists conduct research in schools through close collaboration and consultation with practitioners, such as school personnel.

Given the concerns about research uptake by school practitioners, mere collaboration may be insufficient. Investigations of problems of practice that emerge *from* classrooms are less common in educational psychology. Yet, such a shift may facilitate the bidirectional flow that Farley-Ripple and colleagues (2018) described because it would require that the experiences and expertise of partners, such as researchers and school personnel, mutually inform the questions that are asked and the way studies are developed. In this way, educators may claim more ownership of the solutions that emerge from their experiences and practices.

The main objective of this book is to explore early mathematical learning and cognition from interdisciplinary perspectives. The book aims to make a holistic contribution to understanding the conditions under which children sharpen and extend their mathematical thinking in a variety of settings. We are particularly proud of the contributions to this edited volume. They reflect interdisciplinary perspectives that are, in our view, appropriate springboards for conversations about bidirectionality in educational research. The studies intentionally borrow from different disciplines, but also reside in both research and practice, with clear implications for practice—whether that is in home settings, preschool settings or schools.

The three sections of the book are organized around developmental periods in cognition: (1) infancy and preschool; (2) the beginning of formal schooling; and (3) elementary education. Our first section, infancy, and preschool, begins with this chapter and then a chapter by Makosz, Zambryzcka, and Kotsopoulos, who explore what they define as the “girl crisis.” Early childhood origins of gender differences and future mathematics learning and participation are explored. The authors draw from the extant literature, including their own. Evidence is explored to consider whether different patterns of participation are motivated by cognitive, behavioral, attitudinal, or socialized differences. Of considerable interest are their reflections on the role of males, including fathers, in what we understand about gender differences and the learning of mathematics. Their analysis suggests a lack of conclusiveness

about gender gaps and a fade effect showing that these gender differences diminish as children progress through the school years.

In Chap. 3, Lee, Hodgins, and Wood address spatial learning, technology, and the role of parental talk. With technology-enhanced toys being widely available to parents, this contribution is timely. The authors introduce the important differences in spatial talk during technology-based play versus play with traditional manipulatives and discuss ways to capitalize on the affordances offered by each to enhance children's spatial learning.

In Chap. 4, Linder describes a five-week take-home "mathematics bags" intervention designed to support and increase mathematics play interactions between parents and preschool-aged children. The bags focused on various mathematics strands and were designed to encourage mathematical inquiry in the home. Linder found high levels of engagement and interest for both children and parents. Moreover, the intervention demonstrated to other practitioners the efficacy and feasibility of such an initiative.

Our second section, addressing the beginning of formal schooling, starts with a contribution from Penner, Buckland, and Moes, who explore early identification and interventions for kindergarten children at risk of mathematical difficulty. Using research from longitudinal studies, these authors identified cognitive predictors of numeracy skills and then identified evidence-based early screening tools for teachers and researchers. This interdisciplinary work illustrates how such interventions can happen in classrooms, with the ultimate goal of improving the long-term outcomes of students.

In Chap. 6, Kotsopoulos, Floyd, Nelson, and Makosz examine the differences between mathematical thinking and computational thinking. As the authors point out, many young children begin school as significant users of technology and as such, computational thinking is a topic of great interest among educators and innovators alike. To explore differences between mathematical and computational thinking, kindergarten children's free play was examined. Instances of free play that were viewed as computational thinking were captured by teachers using digital devices and then subsequently analyzed collaboratively by the teachers and the researchers. Considerable overlaps between mathematical and computational thinking were discovered, and teachers also enhanced their understanding of the distinctions between both types of thinking.

In Chap. 7, Osana and Pitsolantis explore the meaningful use of manipulatives in kindergarten. These authors investigate the instructional conditions that support the development of children's dual representation of manipulatives and the moderating effects of prior numeracy knowledge. An important finding was that children with higher prior knowledge were more successful at transferring their learning between different types of tasks and demonstrated superior performance on an application task.

In Chap. 8, Sevinc and Brady share classroom-based research that involved a three-phased instructional cycle: (a) narrative introduction, (b) model development, and (c) model sharing. The aim was to explore the extent to which activities elicited model representations of length and area. This chapter illustrates how young learners

are capable of developing models representing length and area through the use of story, inquiry, and collaborative activity conducted in whole-class and small-group settings.

In Chap. 9, Wijns, Torbeyns, De Smedt, and Verschaffel investigate patterning in preschool and kindergarten settings. Patterning is proposed to have an important role in children's mathematical development. The authors share recent research, compare different definitions and operationalizations of patterning, and elaborate on the association between mathematical patterning abilities and other domain-specific and domain-general cognitive abilities. Finally, interventions aimed at stimulating patterning abilities in young children are explored.

The final section of the book focuses on the elementary school years and begins with Chap. 10. Robinson explores the importance of arithmetic concepts and how they fit with children's knowledge of arithmetic facts and arithmetic problem-solving procedures. A review of how concepts are assessed by researchers is presented as well as current research on the development of six specific arithmetic concepts: identity, negation, commutativity, inversion, associativity, and equivalence. Robinson explores several ways in which teachers and parents can increase children's understanding of arithmetic and promote the use of that knowledge to improve their mathematical skills.

In Chap. 11, Martínez articulates a theoretical framework based on situated cognition and one from sociolinguistics about second language education (i.e., communicative language teaching) to understand mathematics language integration. Using classroom examples, Martínez illustrates how pedagogical practices consistent with a situated perspective on mathematics education provide opportunities to engage with the second language and how pedagogical practices consistent with a communicative perspective on second language education provide opportunities to engage in mathematical activity.

In Chap. 12, Desmarais, Osana, and Lafay present an interesting chapter related to children who have learning difficulties or intellectual disabilities. The authors engaged in a classroom-based intervention called schema-based instruction (SBI; Jitendra & Star, 2011). SBI uses visual representations to teach students the mathematical structure of word problems. The chapter outlines the literature, the intervention, and the results. Their analysis of the ways in which disability intersects with mathematical instruction may account for the students' performance after the intervention.

In Chap. 13, Dubé, Xu, Kacmaz, Alam, and Ren also consider technology; more specifically, their chapter is about the role of tablets as an elementary mathematics education tool for both parents and teachers. As the authors point out, there is little consensus on whether or not tablets are effective tools for teaching mathematics, and studies seem to provide contradictory explanations about their effects on children's learning. This chapter is a systematic literature review of the tablet literature up to grade 5, published between 2012 and 2017.

In our final chapter, Fitzpatrick and Hallett provide a comprehensive review of the literature examining children's early understanding of proportional reasoning and division, and how these early conceptions contribute to children's later understanding

of fractions. Although early literature on proportional reasoning suggested that only adolescents have a true understanding of proportional reasoning, more recent research suggests that very young children, if asked appropriately, do demonstrate a basic or intuitive understanding of proportional structures.

In addition to each chapter reflecting interdisciplinary perspectives on early mathematical learning, each chapter also articulates applications to practice—be it in the home, early learning center, or school. A commitment to articulating application to practice is a significant contribution of this collective work. This commitment is in line with the tenets of this proposed new focus on bidirectionality in educational research. We anticipate the book will be of interest to developmental psychologists, neuroscientists, mathematics teachers, mathematics education researchers, and early childhood researchers and practitioners.

The book would be an ideal text for an introductory course in early mathematical cognition in a variety of disciplines, including psychology, education, educational psychology, educational neuroscience, child development, and cognitive development, particularly given the range of developmental periods, mathematical domains, methodological approaches, and contexts of application that are represented. Our sincere gratitude to our colleague authors who contributed so thoughtfully to this work.

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The “Girl Crisis”: The Relationship Between Early Gender Differences and Future Mathematical Learning and Participation



Samantha Makosz, Joanna Zambrzycka and Donna Kotsopoulos

There is a dominant view in society that early participation in the areas of science, technology, engineering, and mathematics (STEM) is an important gateway to a successful future—both professionally and financially. Evidence from a variety of studies supports this perspective (Change the Equation, 2017; Conference Board of Canada, 2014). By the end of high school and within most STEM-based disciplines, a gender difference in terms of participation is evident. More young men than women choose to study in STEM-based disciplines in a post-secondary setting at the end of high school (You, 2013). Further, women are less likely to choose a STEM program in post-secondary, regardless of mathematical achievement in high school (Hango, 2013a), though by the end of high school, males’ mathematics scores are higher than females’ (Hango, 2013b). In advanced graduate education in STEM disciplines, men are overrepresented in most fields of study (Gillen & Tanenbaum, 2014). Indeed, by the end of high school, one might argue that a “girl crisis” emerges in STEM education that has serious implications for women in terms of future career prospects and economic prosperity.

Our focus in this chapter is to explore the early childhood origins of this trajectory, drawing from the extant of the literature and also referring to our own recent research. We explore the evidence to consider whether different patterns of participation are motivated by cognitive, behavioral, attitudinal, or socialized differences. Specifically, we will examine gender differences and similarities, reasons for gender differences (perception and beliefs, parent and teacher influences, gender stereotypes, and interest and motivation), and the lack of representation of males and fathers in research.

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K. M. Robinson et al. (eds.), *Mathematical Learning and Cognition in Early Childhood*,
https://doi.org/10.1007/978-3-030-12895-1_2

In addition, we will discuss the lack of conclusiveness in some of the gender gap research.

Gender Differences and Similarities

Children's mathematical knowledge begins to develop much sooner than the start of formal schooling (Resnick, 1989). Infants as young as six months are sensitive to numerosities (Starr, Libertus, & Brannon, 2013; Xu & Arriaga, 2007; Xu & Spelke, 2000; Xu, Spelke, & Goddard, 2005), but studies that have focused on infants typically do not take into account the role that gender may play. One study by Starkey (1992) looked at gender and infants by examining addition and subtraction concepts in 18- to 42-month-year-olds, but found no gender differences. A key issue when attempting to detect gender differences in infants is the sample size across studies. For instance, Spelke (2005) explains that most studies on infants do not report gender differences because of the lack of effects and that infant studies have not been incorporated in more powerful analyses such as meta-analyses.

The research on preschool- and kindergarten-aged children presents mixed findings on gender differences. Ginsburg and Russell (1981) found that the only gender differences for four- to five-year olds were in addition and subtraction tasks, with girls performing better, but the study consisted of a small sample of children. However, studies that have incorporated larger samples with this age group have not found gender or cultural differences on various numerical tasks, such as counting or arithmetic (Lummis & Stevenson, 1990; Song & Ginsburg, 1987). From these findings, there is little evidence to support gender differences in emergent numeracy abilities from infancy to four years of age.

To accurately detect gender differences, sample size needs to be considered. Studies that have examined mathematics achievement from the Early Childhood Longitudinal Study, Kindergarten Class of 1998–1999 (ECLS-K), which is a nationally representative sample (approximately 21,400 kindergarteners) in the USA, found that overall, there are no significant gender differences in mathematics at the start of kindergarten (Penner & Paret, 2008; Robinson & Theule Lubienski, 2011). Conversely, Penner and Paret (2008) did find gender differences at the start of kindergarten in favor of males among those at the top distribution of the 95th percentile, while a female advantage was present at the lower end of the distribution (1–40th percentile). Notably, when examining the top scores for kindergarteners' mathematics achievement, only 15% of females were in the top 1%. By eighth grade, 37% of females were in the top 1% (Robinson & Theule Lubienski, 2011). Although an increase is promising, this underrepresentation may account for the gender disparity of females in mathematics-related careers, given that females still only represent a third of the top achievers by eighth grade.

Further data from the ECLS-K demonstrated that parental education has a mediating effect on the male advantage found in kindergarten mathematics. The sons of parents with higher education levels had the greatest advantage; however, males

from lower parental education levels still sustained an advantage when compared to females. Females at the bottom of the distribution had similar results regardless of parental education levels. By the time students progressed to the third grade, there was no longer a female advantage for those in the lower end of the distribution, and the male advantage had spread throughout the distribution (Penner & Paret, 2008).

Husain and Milimet (2009) coined the term “boy crisis,” which makes reference to the fact that boys are lagging behind girls across multiple academic fields, except for mathematics. Husain and Milimet used the data from the ECLS-K and found that, by the start of kindergarten, males are marginally outperforming females, but by the end of kindergarten, this gender gap doubles. Likewise, the gap continues to double until the end of third grade. It is important to note that this early male advantage was predominantly related to white males, and the same results were not found with African–American or Hispanic children.

While it appears that boys are outperforming girls at the top of distribution, the findings are inconsistent when assessing participants’ complex mathematical problem solving versus less complex mathematical tasks (e.g., computation). A meta-analysis conducted by Hyde, Fennema, and Lamon (1990) examined 100 studies and demonstrated that children as young as five years old do not show gender differences on more complex mathematical problems, but that males outperformed females in high school on similar measures. The meta-analysis did find that by grade two, girls have better mathematical computation and problem solving skills than males, but by the time students reach high school, males have better problem-solving skills (Hyde et al., 1990). In another study, Pargulski and Reynolds (2017) examined mean and variance differences on mathematical problem solving and numerical operations for over 2000 participants between the ages of 4–19. The authors found a significant male advantage for those categorized as high performers on problem solving, but they did not examine at what age these gender differences emerge. Pargulski and Reynolds did not find a gender difference for numerical calculations. Overall, the emerging gender gap in complex mathematical problem solving is troublesome, given the need for complex skills in order to enter STEM occupations.

Other studies have not necessarily found differences between boys’ and girls’ mathematical abilities, but have demonstrated differences in growth of mathematical abilities. For instance, Aunola, Leskinen, Lerkkanen, and Nurmi (2004) found no differences from preschool to the second grade using a sample of almost 200 Finnish students, but males showed a faster increase in performance compared to females and had more variability in their performance. For those who were ranked with high ability in mathematics in kindergarten, their gender was able to predict their performance in the second grade. Counting ability was also a predictor of mathematical performance. This finding highlights that girls may benefit from more exposure to and practice with counting, particularly prior to the start of formal schooling.

The most recent meta-analysis of over seven million American students from grades two to eleven did not find any gender differences on standardized American mathematics assessments (Hyde, Lindberg, Linn, Ellis, & Williams, 2008). Standard school assessments have been criticized for assessing lower-level mathematical skills; thus, consequently, the authors also examined data from the National Assess-

ment of Educational Progress (NAEP), which includes more complex mathematical problems. The findings showed that by high school, females demonstrated similar performance to males. In comparison with the meta-analysis (Hyde et al., 1990), the NAEP data appear to show that gender differences in complex problem solving are disappearing.

Given that the research suggests that gender differences diminish with age, it may be that students' motivational levels explain why females are less likely to pursue mathematics in their future education and careers (Hyde, 2014). A review of various meta-analyses proposed a gender similarity hypothesis in mathematics, whereby there are more gender similarities than differences (Hyde, 2014). One area of mathematics that Hyde (2014) suggested has moderate gender differences is in 3D mental rotation, found in children as early as four years old, with a male advantage (Levine, Huttenlocher, Taylor, & Langrock, 1999).

Other researchers have hypothesized that gender differences are disappearing because of changes to education policies, such as No Child Left Behind (Cimpian, Lubienski, Timmer, Makowski, & Miller, 2016). In response, Penner and Paret (2008) analyzed the ECLS-K: 2011 dataset and found that gender results were remarkably similar to the 1999 dataset. Females are still less than one-third represented at the top of the distribution as early as in the spring of kindergarten, thus suggesting that these differences emerge before the start of kindergarten and may indeed be more influenced by environmental factors.

A common limitation among the meta-analyses conducted is that the studies included often lack samples that include children prior to the start of formal schooling. Robinson, Abbott, Berninger, and Busse (1996) prescreened children during preschool in order to examine children with high mathematical abilities. They found that on standardized mathematical tests, boys scored higher than girls on most of the quantitative measures. Nevertheless, the gender results found for this study were not based on the whole sample of students, and thus, there is a lack of generalizability to young students of various mathematical abilities.

Reasons for Gender Differences

Researchers have attempted to tease apart the underlying causes for observed gender differences in mathematics, arguing they are more complex than the nature versus nurture debate. In fact, there are a variety of factors that interact with one another such as psychology, biology, and socialization, along with environmental factors, attitudes, and beliefs (Halpern, Wai, & Saw, 2005; Jacobs, Lanza, Osgood, Eccles, & Wigfield, 2002; Wood & Eagly, 2002). Other reasons that have been proposed to explain why gender differences in mathematics emerge in the first few years of formal schooling include perception and beliefs, parent and teacher influences, lack of representation of males and fathers in research, gender stereotypes, and interest and motivation (e.g., Dickhauser & Meyer, 2006; Eccles, Wigfield, Harold, & Blumenfeld, 1993; Fredricks & Eccles, 2002; Gunderson, Ramirez, Levine, & Beilock, 2012; Jacobs &

Eccles, 1992; Neuburger, Jansen, Heil, & Quaiser-Pohl, 2012). These factors will be further discussed throughout the chapter.

Perception and Beliefs

Some researchers have found that males and females start school with the perception that they have strong abilities in mathematics (Bouffard, Marcoux, Vezeau, & Bordeleau, 2003; Eccles et al., 1993), though this perception changes as children continue through elementary school. In a meta-analysis across a variety of ages, females typically report negative attitudes toward mathematics (Hyde et al., 1990). By the first grade, males have reported higher perceptions of their mathematical abilities compared to females (Eccles et al., 1993).

Furthermore, Dickhauser and Meyer (2006) reported that males and females between the ages of eight to nine years have different perspectives concerning their personal attributions to mathematical ability. In this study, girls were more likely to attribute failure in mathematics to their low ability; conversely, they were less likely to attribute mathematical success to high ability. Additionally, girls did not consider their actual mathematical performance (i.e., grades) when concluding their ability attributions, even though their performance was usually positive. Boys did incorporate their actual mathematical performance when deciding their ability attributions. This implies that children at the elementary level have developed their own perceptions of their mathematical ability and why they are or are not good at mathematics, and that girls appear to have low confidence in their mathematical ability.

Parent and Teacher Influences

Parents have their own perceptions regarding their children’s attributes. This is important because if females at a young age are less interested in mathematics and perceive that their parents do not value their competence in mathematics, they are less likely to pursue mathematics in the future (Jacobs, Davis-Kean, Bleeker, Eccles, & Malanchuk, 2005).

Research has found that mothers from the USA, Korea, Japan, and Taiwan tend to believe that their sons are better at mathematics; consequently, mothers have higher expectations for their sons in comparison with their daughters (Lummis & Stevenson, 1990). Parents are also more likely to attribute their eight- to nine-year-old daughters’ success in mathematics to their effort and their sons’ success to talent (Yee & Eccles, 1988). This perspective underestimates daughters’ abilities, which in turn leads young girls to potentially underestimate their own ability. Girls may not be given the same confidence as boys. Interestingly, fathers have higher standards for boys who already have low mathematical abilities than for girls (Yee & Eccles, 1988). This perspective appears to be true among teachers as well, where males’ failures in mathematics are attributed to lack of effort, but for females, their failure

is attributed to lack of ability (Fennema, Peterson, Carpenter, & Lubinski, 1990; Tiedemann, 2000).

Although one study that examined parents' perceptions of their children from kindergarten to the third grade found no gender differences in their beliefs, parents believed mathematics was more important for their sons than for their daughters (Eccles, Jacobs, & Harold, 1990). Many of these studies are almost three decades old, and efforts have since been made to highlight the need for females to partake in mathematics (Change the Equation, 2017).

There is ample research that supports teachers as socializing agents in children's mathematical abilities and beliefs (Beilock, Gunderson, Ramirez, & Levine, 2010; Else-Quest, Hyde, & Linn, 2010; Gunderson et al., 2012; Upadaya & Eccles, 2014). Therefore, it is vital for teachers to be aware of their own mathematics anxieties and beliefs, particularly because of the influence it may have on their students. For example, one study examined first-grade teachers who exhibited mathematics anxiety and found that the teachers' female students performed more poorly in mathematics than males, which was mediated by the students' own ability beliefs; there was no influence of anxiety on first-grade males (Beilock et al., 2010).

Lack of Representation of Males and Fathers

Interestingly to note, studies that include teachers and parents tend to include more female teachers and mothers. Beilock et al. (2010) analyzed only female teachers' mathematics anxiety, with a rationale that over 90% of teachers in the USA are female. Many studies examining only gender differences do not report which caregiver consented to participate, but those that include caregivers tend to only include mothers, with the justification that mothers typically respond to participate and spend the most time with their children.

In addition, Lummis and Stevenson (1990) interviewed only mothers of kindergarten children with the reasoning that it would be too difficult to find the time to interview fathers. Jacobs and Eccles' (1992) study was from a larger study (Michigan Study of Adolescent Life Transitions), where both mothers and fathers were asked to participate, but the authors used mothers as the sample given that more mothers returned the survey questionnaires. No comparison numbers were provided in the study, though the authors stated that similar results were found with fathers, which were not presented in the paper.

Another large dataset is the Childhood and Beyond study, which started in 1983 and includes both cross-sectional and longitudinal information on children from kindergarten to grade three (Jacobs et al., 2005). Both fathers and mothers responded to various survey questions about their beliefs and interests and how often they engage in mathematical activities with their child. Jacobs and colleagues (2005) used the Childhood and Beyond dataset to track children longitudinally from kindergarten to grade three and to track parent involvement and parents' perception in mathematics, along with other influencing factors.

Although the Childhood and Beyond dataset includes survey reports from fathers and mothers, mothers were used for the majority of the analyses because more mothers completed the surveys. For example, when examining what sorts of toys parents buy for their child, they asked mothers instead of fathers, reasoning that mothers are more likely to do the shopping. The mothers reported buying more mathematical toys for their sons compared to daughters. This implies that boys may have more opportunity and access to mathematical play experiences. Yet, mothers and fathers were more likely to report being involved with mathematical activities with their daughters, possibly because they believed their daughters needed more guidance in the area (Jacobs et al., 2005).

Simpkins, Fredricks, and Eccles (2015a) used the Childhood and Beyond dataset most recently and reported a total of 987 children, with 723 mothers and 541 fathers. In their study, they focused on the larger sample with mothers because of higher statistical power. They also included a section of fathers, arguing that it was necessary because of the dearth of research with participating fathers or data being indirectly collected about fathers. Fathers’ behaviors predicted their child mathematical abilities starting in grade two, but mothers’ did not, which may be explained by the stereotype of who is “better at” and who values mathematics. Simpkins, Fredricks, and Eccles (2015b) explained that they “could not directly test for mother and father differences and that the samples of mothers and fathers are drawn from overlapping, but not equivalent families” (p. 135), thus emphasizing the challenge of collecting data from fathers even over a longitudinal study spanning more than 12 years. More recent meta-analyses are needed to understand the influence fathers have on their children, given that fathers spend more time with their children when the mother is employed outside the home (Sandberg & Hofferth, 2001).

In our own research, we considered the same sorts of questions about mothers and fathers and their engagement with their young children. Eighteen mother–child dyads between the ages of two to five years old ($M_{\text{age}} = 39.39$ months; $SD = 15.38$; 10 boys) and 18 matched sample father–child dyads also between the ages of two to five years old ($M_{\text{age}} = 39.72$ months; $SD = 15.07$; 10 boys) participated in the study. Parents completed a demographic questionnaire, a mental rotation task (MRT; Vandenberg & Kuse, 1978), and two activity surveys adapted from Dearing and colleagues (2012) exploring spatial (e.g., building with blocks, puzzles) and mathematical activities (e.g., sing counting songs) in the home. Children’s nonverbal quantitative reasoning was measured by the Stanford-Binet Intelligence Scales for Early Childhood, Fifth Edition (SB5: Roid, 2003). The Nonverbal Quantitative Reasoning subtest contains 18 items that require the child to answer questions based on quantity size, nonverbal mental addition, number recognition, estimation, three-dimensional block counting, and the relative magnitude of numbers.

Mothers were found to be more likely to report teaching their sons mathematics compared to their daughters. There were no significant differences in what fathers reported about their interactions with their daughters relative to their sons. A possible explanation for this may be that mothers typically spend more time with their children at home, thus are better able to report who they teach more often.

Correlational analyses were conducted separately for mothers and fathers to determine any associations between their child's quantitative reasoning and a variety of cognitive and social factors. The first set of correlational analyses were conducted with the mother-child dyads and explored the relationship between children's non-verbal quantitative reasoning to the following factors: child's age, gender, mother's education level, mother's mental rotation scores, at home teaching activities, and the frequency of spatial activities, including overall average frequency and the frequency of each spatial activity. The correlational analyses for the mother-child dyads found child's gender to be significantly correlated with their quantitative reasoning ability ($r = 0.52$, $p = 0.02$), indicating that girls were more likely to outperform the boys. For the father-child dyads, the correlational analyses revealed that child's age ($r = 0.55$, $p = 0.01$) and the frequency with which they engaged in building with construction toys ($r = 0.56$, $p = 0.01$) were significantly correlated with their quantitative reasoning scores. This indicates that as children aged their quantitative reasoning scores improved and children who played more often, with construction toys had higher quantitative reasoning scores. Our own results, therefore, support the notion that gendered engagement in the home by mothers, but not by fathers, is evident before formal schooling.

Gender Stereotypes

Gender stereotypes emerge early (Gelman, Taylor, & Nguyen, 2004). In conversation, subtle messages (i.e., reference to categories of gender, labeling of gender, and contrasting males vs. females) about gender by mothers can have an influence on their toddlers' gender beliefs (Gelman et al., 2004). In turn, the numeracy performance of children as young as five years old is influenced by such stereotypes (Ambady, Shih, Kim, & Pittinsky, 2001). Specifically, five-year-old Asian-American girls performed worse on a numeracy task when their gender identity was activated.

In kindergarten, females are also susceptible to stereotype threat, given that they are more likely to perform worse on a mathematical task when their gender stereotype is activated—mothers who view mathematics as a field that is male dominated are more likely to have daughters who perform worse on mathematical tasks (Tomasetto, Romana Alparone, & Cadinu, 2011). Additional research by Tomasetto, Mirisola, Galdi, and Cadinu (2015), who studied 253 six-year-olds (131 girls and 122 boys), and both their mothers and fathers, found that daughters' math self-perception was predicted by their mother's math stereotypes. However, both mothers and fathers did not differ in their math-gender stereotypes according to the gender of their child, though fathers were more likely to endorse math as a male-dominated field. Moreover, there was an association between fathers' evaluations of their child's ability and children's self-perception of ability. This was significant even after controlling for the effect of mothers. These findings shed light on the important influence of fathers, who are often underrepresented in the research.

More evidence examining children in grades one, two, and four highlighted the development of gender stereotypes (Freedman-Doan et al., 2000). Both males and females provided gender-stereotyped answers when asked what task they were the worst at. The majority of females stated science and computers, while males stated reading. In relation to mathematics, females stated less often that they were good at mathematics compared to males. Nonetheless, both genders believed they could improve on the task that they believed to be the worst at, but by the fourth grade, most students believed that they could not improve. Their reasoning for not being able to improve was attributed to lack of ability. This finding verifies that as children of both genders get older, they presume they are less capable of improving in their worst qualities (Freedman-Doan et al., 2000). Further, it suggests that early on, students are more confident in their abilities, but as they go through formal schooling, their self-efficacy decreases.

Interest and Motivation

Children’s mathematical interest at the start of formal schooling is vital, as the higher the mathematical interest displayed by the child, the more likely teachers attribute their success to effort and ability, which then results in an increase in children’s interest in mathematics (Upadyaya, Viljaranta, Lerkkanen, Poikkeus, & Nurmi, 2012). In one study, children’s mathematical interest was tracked from kindergarten to grade six and teachers’ perception of students’ perceived performance, and effort was the most consistent factor in students’ motivation throughout the years (Upadyaya & Eccles, 2014); there were no differences between genders with regards to children’s interest and teacher beliefs, however. Nevertheless, both genders were equally sensitive to teacher feedback.

Early motivation is also imperative, as those who display higher mathematical motivation at the start of kindergarten perform higher on an arithmetic assessment at the end of the school year, without showing any gender differences (Viljaranta, Lerkkanen, Poikkeus, Aunola, & Nurmi, 2009). This is consistent with other studies that have not found gender differences in mathematical motivation at the start of formal schooling (Jacobs et al., 2002). Unfortunately, by the third grade, girls’ motivation tends to decrease, but boys’ motivation remains stable (Bouffard et al., 2003). This may explain why boys with high mathematical abilities in kindergarten have significantly increased in their abilities by the third grade, whereas girls have not (Husain & Millimet, 2009).

Children need to engage in mathematical play prior to the start of formal schooling, so they enter kindergarten with an interest and motivation in mathematics. Gender differences in mathematical motivation do not exist in preschool (Viljaranta et al., 2009), which implies that prior to the start of formal schooling, both genders are equally motivated in mathematics.

Conclusion

Overall, the literature that has examined gender differences in mathematical abilities prior to formal schooling suggests that they may be more socialized than innate. The most substantial studies examining gender differences begin in kindergarten and only find a male advantage at the top of the distribution. The most recent meta-analysis (Hyde, 2014) found that gender differences are disappearing: “nonsignificant gender difference, that is, a gender similarity, is as interesting and important as a gender difference” (Hyde, 2014, p. 393).

Awareness of gender similarity in mathematical ability is an important and critical mind shift that is necessary. Early childhood experiences at home are crucial, and more research is needed to examine how fathers spend time with their children. Awareness of gender similarity in mathematical ability is also an important mind shift for schools. One implication of this review is that parents, caregivers, and educators need to be informed of the importance of creating equal mathematical opportunities for both boys and girls, not only at an early age, but throughout childhood. Although most parents and teachers would readily agree that mathematical learning is important, the extent to which the adults recognize their own biases in their interactions with children may be limited.

The subversive nature of systemic gender bias in mathematical engagement, which results in under participation of women in post-secondary STEM disciplines, regardless of ability, consequently impacts women’s future career choices, financial security, and health access, particularly in the USA, where health care is less accessible for low-income earners and their futures as women are more likely to be as single parents (Andersen & Newman, 2005; US Census Bureau, 2016). This demonstrates precisely how complex and yet utterly necessary it is to frame the situation as both a “girl crisis” and one of gender similarity.

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