CHAPTER 2

SUPPORTING SCIENCE, TECHNOLOGY, ENGINEERING, AND MATHEMATICS (STEM) LEARNING BY HELPING FAMILIES OVERCOME MATH ANXIETY

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A mother sits down to help her child with homework. As the child pulls out a worksheet covered in numbers, the mother lets out a small groan.

"Not more math homework!" she exclaims. "Math is so hard." The mother takes the worksheet from her child's hands and starts to look over the questions. She talks through how to solve each of the problems as her child sits next to her, listening attentively. As each problem is solved, the child writes in the answer before moving on to the next one. Before they know it, the worksheet is done.

"Phew," says the mom, "I expected that to be a lot worse. I can't wait until you don't have to take any more math classes."

Promising Practices for Engaging Families in STEM Learning, pp. 19–34

The scene described above exemplifies the kinds of mathematics interactions that children of parents with high math anxiety may encounter at home. Small, seemingly mundane exchanges like these can have broad implications for children's mathematical achievement and their likelihood of pursuing science, technology, engineering, and mathematics (STEM) academic and career paths.

As a cornerstone of the STEM domains, a firm grasp of basic mathematical concepts is a crucial component for success in school, the workplace, and everyday life. Although early mathematical skills are a strong predictor of later mathematical achievement, somewhat surprisingly they are also a strong predictor of later reading achievement—even more so than early reading achievement (Duncan et al., 2007). This relationship between early mathematical skills and later academic success across domains may be explained by the higher order thinking skills necessary for success at mathematics, even during the early childhood years. Unfortunately, in the United States, achievement in mathematics is stagnating—students have not shown significant improvements in mathematics in the past 10 years (National Assessment of Educational Progress, 2015), and continue to fall behind their peers in other developed countries, placing 31st among 35 countries on the 2015 PISA test (Organisation for Economic Co-operation and Development, 2016).

Within the United States, differences in mathematical achievement are present early in life. Individual variations in mathematical knowledge emerge prior to kindergarten (Clements & Sarama, 2007; Entwisle & Alexander, 1990; Griffin, Case, & Siegler, 1994; Klibanoff, Levine, Huttenlocher, Vasilyeva, & Hedges, 2006; Starkey, Klein, & Wakeley, 2004) and tend to persist as children progress through school. Children from lower socioeonomic backgrounds are more likely to show early gaps in mathematical knowledge, and these gaps tend to widen over the years (Jordan & Levine, 2009; Levine, Gunderson, & Huttenlocher, 2011; Reardon, 2011). By high school graduation, children from families in the lowest socioeconomic status (SES) decile lag behind their higher income peers by a difference of approximately one standard deviation in mathematical achievement (Reardon, 2011). Addressing the SES-related mathematical achievement gap is closely related to issues of equity given projections of rapid growth in STEM-related job opportunities (U.S. Department of Education, 2016; Vilorio, 2014).

Given the early emergence and persistence of gaps in mathematical knowledge, it is essential to identify the experiences that relate to children's early mathematical development, and to find ways to provide all children with these positive mathematics-related experiences. To that end, in this chapter, we focus on how parents can effectively support children's early mathematical development, and the factors that can undermine this

support, notably parents' math anxiety—the fear and apprehension of doing mathematics (Ashcraft, 2002; Hembree, 1990; Richardson & Suinn, 1972)—and its intergenerational effects on children's mathematical learning and attitudes. We then provide suggestions for how math anxious parents can best support their children's mathematical learning.

THE IMPORTANCE OF EARLY PARENT MATHEMATICS ENGAGEMENT

Because differences in mathematical knowledge emerge before schooling even begins, it stands to reason that the supports parents provide—or do not provide—to their children may play a role in these differences. In fact, the amount and quality of number talk that parents engage in with their children at an early age, controlling for other talk and family socioeconomic background, predicts children's attainment of early foundational mathematical concepts, such as understanding the cardinal principle (e.g., when counting a set of objects, the last number in the counting sequence names the quantity for that set; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010). Further, the spatial talk parents engage in with their children—for example, talk about dimensions (e.g., "tall," "short"), shape (e.g., "rectangle," "triangle"), and spatial features (e.g., "straight," "curved")—supports children's own spatial language production and their performance on nonverbal spatial tasks (Pruden, Levine, & Huttenlocher, 2011). In addition to these aspects of math talk, the frequency and variety of mathematical activities in which parents engage their children at home are also related to later mathematical knowledge (e.g., LeFevre et al., 2009; Skwarchuk, Sowinski, & LeFevre, 2014).

Although parents serve as a child's first mathematics teacher, making them undeniably critical to the development of their children's mathematical knowledge prior to entering school, parental involvement remains an essential component of children's educational achievement even once formal schooling begins (e.g., Fan & Chen, 2001; Hill & Taylor, 2004; Jeynes, 2003, 2005). However, parents' engagement in mathematics-related activities with their children can have unintended negative consequences. For example, there is much variability in the quality of mothers' scaffolding of material when helping their children with homework (Hyde, Else-Quest, Alibali, Knuth, & Romberg, 2006), and low quality mathematics interactions might lead children to develop negative attitudes about mathematics, and may even confuse them about the mathematical concepts and procedures they are learning in school (Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015).

Although different factors contribute to the varying quality of parent-child mathematics interactions (e.g., mathematical ability, time, interest, etc.), research most strongly implicates parental attitudes, such as parents' expectations for their children's success in mathematics, and the value (or importance) they place on the material being studied as having the largest effect on children's learning in mathematics (e.g., Grolnick & Slowiaczek, 1994; Hill & Tyson, 2009). Over the past several years, we have explored the impact of another parent attitude, math anxiety, on parent-child mathematics interactions.

WHAT IS MATH ANXIETY?

Math anxiety has implications both in academic settings, such as taking a mathematics test, and in everyday settings, such as calculating a tip at a restaurant (Ashcraft, 2002; Ashcraft, Krause, & Hopko, 2007; Ashcraft & Moore, 2009). People around the world experience math anxiety (Foley et al., 2017), and as much as 20% of the U.S. population, including nearly half of community college students, is estimated to experience high levels of math anxiety (Eden, Heine, & Jacobs, 2013; Sprute & Beilock, 2016). Of note, the occurrence of math anxiety tends to be higher among females than males, with this sex difference emerging by sixth grade (Hembree, 1990). Generally, math anxiety is not thought of as a binary attribute, but rather is measured as a continuous variable, by asking people to rate how anxious various mathematics-related experiences make them feel (ranging from "not at all anxious" to "very much anxious"; see Box 1 for examples of math anxiety scales). Many people may experience some anxiety about mathematics in specific situations but still fall at the lower end overall on a measure of math anxiety (see Box 1).

Math anxiety is evident as early as first grade (e.g., Harari, Vukovic, & Bailey, 2013; Ramirez, Gunderson, Levine, & Beilock, 2013; see Box 1 for example of a math anxiety scale used with children), increases across schooling (Hembree, 1990), and is linked to poor performance in mathematics (Ashcraft, 2002). Although experimental evidence shows that math anxiety is causally linked to lower mathematical performance, this may also be a bidirectional relationship, with lower mathematical performance leading to increased math anxiety (Beilock, Schaeffer, & Rozek, 2017; Gunderson, Park, Maloney, Beilock, & Levine, 2018).

Although math anxiety is associated with poor performance in mathematics, it is not simply a proxy for poor mathematical ability (Faust, Ashcraft, & Fleck, 1996; Jamieson, Peters, Greenwood, & Altose, 2016; Park, Ramirez, & Beilock, 2014). In fact, math anxiety exists across the

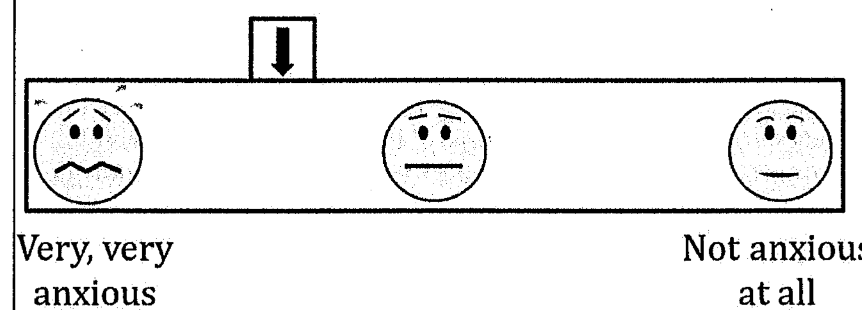
Box 1.
How is Math Anxiety Measured?

Math anxiety is measured using a questionnaire where each item represents a situation that may make a respondent feel anxious. Questions include highly academic scenarios such as "How do you feel when getting ready to study for a math test?" or describe everyday situations like, "How do you feel when reading a cash register receipt after your purchase?" Respondents are asked to rate the level of anxiety they associate with each item, from 1 ("not at all") to 5 ("very much").

Selected scales available to measure math anxiety in adults:

- The Mathematics Anxiety Rating Scale (MARS; Suinn, 1972), a 98-item instrument, was among the first instruments developed to assess math anxiety.
- An abbreviated version, the Short-Mathematics Anxiety Rating Scale (sMARS) was developed by Alexander and Martray in 1989. This scale contains 25 items, making it less cumbersome to use than its longer counterpart.
- Most recently, the Single Item Math Anxiety (SIMA) Scale, which is highly correlated with the sMARS, was developed by Núñez-Peña, Guilera, and Suárez-Pellicioni (2014). As indicated by its name, this scale contains only one item: "On a scale of 1 to 10, how math anxious are you?" The anchors for the scale are 1 (not anxious) and 10 (very anxious).

For children, math anxiety questionnaires have been adapted to reflect the mathematics-related situations children encounter in their lives or in school. One such scale, the C-MAQ (Ramirez, Gunderson, Levine, & Beilock, 2013), was designed for use with first and second grade students. Questions include things like: "How do you feel when getting your math book and seeing all the numbers in it?" or "How do you feel when figuring out if you have enough money to buy a candy bar and a soft drink?" Children are then asked to indicate on a smiley-face scale (shown below) how anxious each situation would make them feel.



spectrum of mathematical achievement—even people highly competent in mathematics can be highly anxious about mathematics (e.g., Foley et al., 2017). Further, interventions that ameliorate math anxiety can increase mathematical achievement for math anxious individuals without teaching individuals any additional mathematics (e.g., Park, Ramirez, & Beilock, 2014), indicating that math anxiety is not just about low mathematical ability.

One prominent theory about the relationship between math anxiety and mathematical performance is that the fears and negative emotions that math anxious individuals experience in mathematics-related situations use up cognitive resources, such as working memory, that might otherwise be used on the mathematical task, leading to poor performance (Beilock et al., 2017). Working memory, the ability to keep track of short-term information, may be particularly important when it comes to solving mathematics questions that require holding intermediate steps in mind and computing solutions (Park et al., 2014). Counterintuitively, the negative effects of math anxiety are greatest in individuals with high working memory, and there is evidence that this math anxiety by working memory interaction holds both around the world (Foley et al., 2017) and across ages (Ramirez et al., 2013). We have found that as early as first and second grade, math anxious children who were high in working memory performed more poorly than their high working memory peers who were not math anxious on calculation problems (Ramirez et al., 2013). This was at least partly because they were less likely to use advanced problem-solving strategies—decomposition and retrieval—than children with high working memory who were not math anxious. Instead, these high working memory-high math anxious students frequently deployed the more basic, error-prone strategies (e.g., counting) used by low working memory students (Ramirez, Chang, Maloney, Levine, & Beilock, 2016), likely because their cognitive resources were being taxed by their feelings of anxiety. Taken together, these findings show that math anxiety can compromise the potential of high working memory children to perform at high levels in mathematics. At the same time, when individuals underperform in mathematics, this may increase their anxiety (Foley et al., 2017; Gunderson et al., 2018; Levine, Gunderson, Maloney, Ramirez, & Beilock, 2015). Thus, math anxiety prevents individuals from demonstrating their true ability through a vicious cycle in which math anxiety leads to poor mathematical performance and the poor mathematical performance leads to increased math anxiety.

Math anxiety does not only impact performance on mathematical tasks, it also affects behavior outside of academic situations, leading math anxious individuals to avoid situations where they might encounter mathematics (Ashcraft, 2002; Ashcraft et al., 2007; Hembree, 1990; Maloney & Beilock,

2012). Math anxious individuals tend to take fewer mathematics classes than their non-math anxious counterparts, avoid mathematics-related majors and careers, and may even avoid seemingly mundane activities like calculating a tip at a restaurant (Chipman, Krantz, & Silver, 1992). When math anxious individuals do take mathematics classes, they tend to perform worse in the class than those who are less math anxious (Ashcraft, 2002; Hembree, 1990; Ma, 1999).

Although math anxiety has been shown to negatively affect the mathematical performance of the individuals who suffer from it, we have found that math anxiety also can have intergenerational effects. For example, work in our lab has shown that students of math anxious teachers learn less mathematics over the school year than students of non-math anxious teachers (Beilock, Gunderson, Ramirez, & Levine, 2010). We have also shown that parents' math anxiety matters for students' mathematical learning. Although parents' homework help is generally assumed to be beneficial to students, this is not necessarily the case when parents are high in math anxiety, in part because they are less able to support their children doing mathematics in the home (Herts et al., 2017). In fact, we have found that frequent mathematics homework help to first and second graders by high math anxious parents predicts less mathematical learning over the first or second grade school year both compared to children of high math anxious parents who help less and compared to children of low math anxious parents, regardless of their level of help. Importantly, this relation held controlling for children's mathematical knowledge at the beginning of the school year as well as children's own math anxiety (Maloney et al., 2015). This suggests that the homework help of well-meaning parents can backfire perhaps because their math anxiety makes their homework help less effective even for the relatively basic mathematics homework children are asked to complete in early elementary school. Furthermore, we have found that when parents are math anxious, they provide less number talk to their preschool children, particularly the kinds of number talk that may be most important in driving learning (Berkowitz, Gibson, Monahan, & Levine, 2017; Eason, Nelson, Leonard, Dearing, & Levine, 2017). Together, these findings suggest that math anxiety could lead to differences in both the quantity and quality of teacher-student and parent-child mathematics interactions, and implicate these differences in children's mathematical learning.

Because math anxiety has negative effects both for the math anxious individual and for those in their care, math anxiety can have a broad and reverberating impact. It is important to develop interventions that support both math anxious individuals, as well as the children who interact with these individuals. The next section will delve into recent interventions that hold promise for addressing these issues.

COPING WITH MATH ANXIETY

Researchers have started to develop interventions and supports that can ameliorate the negative impacts of math anxiety. Although interventions that target students directly, including expressive writing tasks, have proven effective in helping math anxious students (Hines, Brown, & Myran, 2016; Jamieson et al., 2016; Park et al., 2014), in this section we focus on interventions that target parents with preschool and school age children. Finding ways to support the home mathematics environment of children with math anxious parents may help ensure that young children have the tools they need to succeed in mathematics. Currently, many parent-targeted interventions are geared toward encouraging parents to increase their engagement in mathematical activities and their math talk with children at home. However, research suggests that this approach may not work if parents feel pushed into doing activities that make them anxious, or feel ill-equipped to guide an interaction with their child, as their involvement is less likely to be sustained, and therefore will have minimal positive effects on children's mathematical learning (Grolnick, 2016; Katz, Kaplan, & Buzukashvily, 2011). Math anxious parents will likely be unhappy during these interactions, creating a negative experience for the child, which could limit the value of the interaction in supporting the child's learning (e.g., Maloney et al., 2015). Creating opportunities for parents to learn or to review the concepts their children are learning in school may boost their feelings of self-efficacy when it comes to engaging their children in mathematics at home. This may especially be true when students are learning to do mathematics in ways that are unfamiliar to parents, a common complaint of parents whose children are learning mathematics with the framework of the Common Core State Standards.

Our research has focused on ways to increase the quality of parent-child mathematics interactions by providing semistructured, age appropriate, and engaging ways for them to engage in mathematical thinking and problem solving together. For example, in one study, we gave parents in the experimental group number books to read with their preschool-aged children and gave parents in the control group similar books that focused on other adjectives (e.g., fuzzy, fluffy). We found that children whose parents were in the number book condition learned the meanings of individual number words, a process that can span months to even years, much faster than expected (i.e., that "two" refers to sets containing two objects), whereas this was not true of the children in the control group (Gibson, Gunderson, & Levine, 2015). Although this study did not focus specifically on parents with math anxiety, this finding suggests that enabling all parents to engage in number talk with their children through the structured environment of picture books can help promote children's understanding of cardinality.

In another randomized controlled study, we looked at whether giving parents a structured, engaging, and low-pressure way to talk to their children about mathematics might help promote children's mathematical learning, especially for children whose parents are math anxious (Berkowitz et al., 2015). In this study, some families were provided with a mathematics app called *Bedtime Math* in the fall of first grade and others were provided with a similar control app focused on reading with their children. Parents in both the experimental and control groups were encouraged to use the app at least four times a week. The app featured daily topical word problems based on holidays and current events, and the passages were developmentally appropriate for young children (see Box 2 for a sample mathematics passage and questions).

At the end of the school year, we found that in the control group, children of highly math anxious parents learned less mathematics than children of lower math anxious parents, consistent with previous findings (e.g., Maloney et al., 2015). However, when families received the mathematics app, children of math anxious parents learned as much as children of low math anxious parents, even though parents' own math anxiety did not change over the course of the year. This finding suggests that math anxious parents might be engaging in mathematics less – or in less effective ways—compared to non-math anxious parents. Further, it shows that with the help of structured mathematical activities—like those provided in the mathematics app or other guided activities that parents and children can do together—this difference can be negated as math-anxious parents engage their children more frequently and effectively in mathematics.

Parents can also help to promote positive motivational attitudes about mathematics by emphasizing and communicating the personal relevance of mathematics to their children (Rozek, Hyde, Svoboda, Hulleman, & Harackiewicz, 2015; Rozek, Svoboda, Harackiewicz, Hulleman, & Hyde, 2017). In a recent study with high school students, one group of parents was given materials and access to a website that explained the relevance of mathematics for their teenagers' everyday lives (e.g., video games, cooking, art, sports, cell phones) and also future careers, while another group of parents was not given any additional materials. Results showed that children of parents with the mathematics-relevance materials took more optional mathematics courses in high school and scored better on the mathematics section of the ACT than children whose parents were in the control group (Rozek et al., 2017). Talking about the relevance of mathematics to young children, such as highlighting how mathematics can be used in everyday activities like setting the table, cooking or recognizing shapes is an approach that holds promise for fostering children's interest and achievement in mathematics from early ages (Harackiewicz, Smith, & Priniski, 2016; Vandermaas-Peeler, Boomgarden, Finn, & Pittard, 2012).

Box 2.
Whipped Cream Gone Wild: Sample Passage and Questions From the *Bedtime Math* App

Whipped cream was invented about 500 years ago, and is credited to a bunch of guys with long unpronounceable Italian and French names. But what made them think to whip up cream in the first place? Did they know what would happen? Never mind that there was no electricity back then—they had to whip it by hand. Luckily, it was worth the effort.

Selected scales available to measure math anxiety in adults:

Whipping air bubbles into cream makes it take up a lot more "volume," or space. In the Bedtime Learning Together test kitchen, 1 cup of heavy cream generated 3 cups of whipped cream. With something as important as dessert, that's a key fact.

Wee ones: If you can whip 2 cups of heavy cream into 6 cups of whipped cream, how many cups of air did you whip into it?

Little kids: If you're making whipped cream for a party, and 1 cup of heavy cream makes 3 cups of whipped cream, how much whipped cream does 6 cups make?

Big kids: If a can of whipped cream holds 6 cups, and when you open it, it kind of explodes and squirts 1 1/2 cups on you, how much is left in the can?

Wee ones: 4 cups of air.

Little kids: 18 cups of whipped cream.

Big kids: 4 1/2 cups.

Thus, with the right materials, parents can help their young children learn basic mathematical concepts at early ages and help their older children stay motivated in mathematics in high school.

IMPLICATIONS AND RECOMMENDATIONS

Research on math anxiety has primarily focused on what it is and how it relates to individuals' performance. However, it is also important to consider the intergenerational effects of math anxiety, and the types of interventions that can be developed to cut the transmission of low mathematical achievement and negative attitudes toward mathematics from adults to the children in their lives. Although parents are encouraged to be more involved in their children's academic work, this can be a daunting (and ineffective) directive for those who suffer from math anxiety. Taking individual attitudes as well as pedagogical and content knowledge into consideration when developing home and school interventions, and constructing professional development for teachers as well as supports for parents are critical components to ensuring increased mathematical achievement and positive attitudes toward mathematics in children.

Given the evidence suggesting an intergenerational link between parents' math anxiety and children's mathematical achievement (Berkowitz et al., 2015; Maloney et al., 2015; Soni & Kumari, 2015), it is critical to create ways to support the mathematics interactions that children have with the adults in their lives. This can be done in a variety of different ways, either through providing models of positive and constructive mathematics interactions or by literally providing a script (as in the case of the mathematics story books and mathematics apps) to guide interactions. Interventions that focus on providing guidance for parents and teachers to praise children in a way that supports the development of growth mindsets through process praise ("Good job on that problem!") rather than person praise ("You're good at math!"), or helping them talk to children about how mathematics is used in everyday life (e.g., cooking, shopping, creating a schedule), may also play an important role in supporting children's mathematical achievement and attitudes toward mathematics (e.g., Gunderson et al., 2017). Teaching parents to avoid saying things like "Math is hard," or otherwise sharing their negative views towards mathematics, and to approach mathematics as an exciting, surmountable challenge, will help children develop positive attitudes towards mathematics as well. Whether this type of support is dispensed through websites (e.g., creating video content to post on YouTube), apps (such as the *Bedtime Math* app discussed here), or even through community mathematics nights, it has the potential for large impacts.

Hopefully, with a little guidance, our opening example of a parent-child mathematics interaction can become more positive and encouraging. Imagine instead …

A mother notices her child struggling with mathematics homework and sits down to help her.

"Let's try to figure this question out together!" she exclaims.

The mother looks at the worksheet and begins to talk through the concepts addressed on the worksheet. She writes out a question, and lets her child attempt to solve it on her own, providing encouragement and guidance when necessary. Once the child understands the main concept, she goes on to solve the questions on the homework sheet. Before they know it, the worksheet is done.

"You did a great job!" says mom. "All your hard work in math is really paying off. I'm excited to see what you learn next!"

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CHAPTER 3

LISTENING FOR STRENGTHS IN DIVERSE FAMILIES' CONVERSATIONS ABOUT SCIENCE

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Educators and education researchers have long argued for the importance of considering students' diverse cultural experiences when designing classroom practices and curricula (González, Andrade, Civil, & Moll, 2001; Gutiérrez, Baquedano-López, & Tejada, 1999; Heath, 1983; Lee, 2006). Science, technology, engineering, and mathematics (STEM) education is an important case in point. The Next Generation Science Standards (NGSS) emphasize that educators should connect school science to students' out-of-school experiences in the home and community contexts to support their engagement in scientific and engineering practices (National Research Council, 2012). Studies have shown that informal parent-child science interactions are opportunities for developing everyday critical thinking practices, even in very young children (Callanan & Jipson, 2001; Haden et al., 2014), and yet we know relatively little about these conversations in diverse families, particularly in the growing population of Latino families in the United States.

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