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THE INFLUENCE OF PARENT MATH ANXIETY ON CHILDREN'S EARLY MATH
INPUT AND KNOWLEDGE

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ABSTRACT

Since young children spend the majority of their time at home, promoting parent-child math engagement could help eliminate early math achievement gaps even before children start formal schooling. However, many adults experience math anxiety – the fear or apprehension of doing math (Ashcraft, 2002) – which may undermine the efficacy of parent-child interactions around math (e.g., Maloney et al., 2015). In three studies I explore the role that parents' math anxiety plays in shaping the exposure that children receive to math at home and ask whether an intervention designed to support parents in talking to their children about math can have a positive impact on children's math learning and achievement.

In Study 1, I find that parent math anxiety impacts the quantity and quality of even the earliest form of parent-child math interactions, parent number talk. In Study 2 I then demonstrate that parent math anxiety relates to differences in a parent's level of involvement in their child's math education as they enter kindergarten, and these differences relate to children's math knowledge at the start of school. Finally, in Study 3 I examine whether introducing a math-related iPad app (which parents and children use together) can help ameliorate the negative effects of parent math anxiety on student achievement. I find that the math intervention promotes student math learning for those students with math anxious parents. The results of these three studies enhance our understanding of the intergenerational impact of math anxiety and demonstrate the importance of cultivating a deeper understanding of the obstacles parents face in engaging in their children's math education in order to develop effective interventions.

1. CHAPTER ONE: Introduction

Parents can be involved in their children’s education in a variety of ways, whether playing games, helping with homework, or enjoying a trip to a museum together. Perhaps because parents are particularly motivated when it comes to promoting their children’s education, increasing parent involvement has long been considered a crucial part of student achievement and school reform (e.g., Hara & Burke, 1998). This idea has gained traction over the years as reflected by the prominence of articles, books, and policies highlighting the importance of parenting styles and involvement (e.g., “Raising a Moral Child;” “Battle Hymn of the Tiger Mom;” Thirty Million Words, etc.). It seems there is an almost overwhelming amount of information directing all parents to become more involved in supporting their children’s academic and social development. However, very little consideration is given to crafting strategies to promote involvement that take into account parent’s individual abilities and limitations. This leaves parents alone with the challenge of discerning the methods and approaches for academic support that best allow them to assist their children. As a result, parents may miss out on helping their children in the most beneficial ways and remain a largely untapped resource when it comes to fostering a child’s academic achievement.

One specific area where it may be particularly beneficial to foster positive parent-child interactions to promote academic achievement is in the domain of math. Early math competency serves as the foundation for future success; not only is math achievement a cornerstone of the STEM (science, technology, engineering and mathematics) domains, but the skills acquired through learning math also have implications for a wide variety of outcomes (e.g., Claessens & Engel, 2013; Duncan et al., 2007; Romano, Babchishin, Pagani, & Kohen, 2010). For example, Duncan et al. (2007) showed that early math skills not only predicted later math achievement,

but also predict later reading achievement even more strongly than early reading achievement. Basic math skills are a necessity for the 21st century workplace, not least because of projections for growth in STEM-related jobs in the coming decades (U.S. Department of Education, 2016; Vilorio, 2014). Furthermore, math skills are relevant to making informed decisions in one's personal life – for example, healthcare, financial, and even political considerations all require some understanding of math.

Unfortunately, children in the United States have fallen behind in their performance in math as compared to other similar countries (Bradbury, Corak, Waldfogel, & Washbrook, 2015; Libertus & Golinkoff, 2017; OECD, 2016). Indeed, data from the National Center for Education Statistics shows that improvement in mathematics in the U.S. has hit an asymptote, showing no real improvements in the past 10 years (Kena et al., 2015; NCES, 2017). And, not only is there a gap between U.S. students and their international counterparts, but there is a pervasive achievement gap in math that is strongly related to a child's socio-economic status (SES; Jordan & Levine, 2009; Levine, Gunderson & Huttenlocher, 2011). Interestingly, variations in basic math 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 (Duncan et al., 2007; MacDonald & Carmichael, 2017; Reardon, 2011; Romano, et al., 2010). Given the early emergence of math knowledge gaps, and the difficulty of closing gaps once they emerge, it is critical to identify the environmental supports that are related to children's early math development.

Since these gaps exist prior to children entering kindergarten, it stands to reason that parents' level of involvement and interaction with their children around math has important

implications for children's achievement later on. Indeed, research has shown that there is considerable variation in the quantity of parent input, and that the variation in the amount of number talk and home numeracy activities in which parents engage their young children is related to their basic math skills when entering kindergarten (e.g. Gunderson & Levine, 2011; Hart & Risley, 2003; Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002; LeFevre et al., 2009; Levine, Gunderson, & Huttenlocher, 2011; Skwarchuk, Sowinski, and LeFevre, 2014). As such, increasing parent involvement and engagement in math at home is touted as a crucial part of student achievement and school reform. However, not all parent-child math interactions are beneficial (e.g. Hyde, Else-Quest, Alibali, Knuth & Romberg, 2006; Maloney, Ramirez, Gunderson, Levine, & Beilock, 2015). A study looking at math homework help with 5th grade students found that mothers varied considerably in the quality of their ability to scaffold the material for their children (Hyde et al., 2006), and these lower quality interactions may not have a beneficial impact on student learning and achievement. (e.g., Maloney, Ramirez, Gunderson, Levine & Beilock, 2015). Therefore, in order to promote and develop appropriate supports for home math engagement, we must also understand the barriers that parents need to overcome in order to have effective math interactions with their children at home.

The purpose of this dissertation is to explore how one specific parent factor, math anxiety, shapes the exposure that children receive to math activities in the home. Chapter 1 will review the role of parents in education, factors that may contribute to variation in parent involvement, and the existing literature on math anxiety. Chapter 2 will present preliminary evidence that math anxiety is related to even the earliest type of math input, number talk to preschoolers in the home. Chapter 3 will further investigate the relation between parent math anxiety and parents' math engagement with preschool-aged children, in addition to considering

parents' spontaneous talk about numbers during a math-related activity, as well as the relation of parents' math anxiety to children's math knowledge at the start of school. Finally, Chapter 4 will consider whether an intervention designed to provide a scripted, low-stakes way for parents to interact with their children around math can ameliorate the negative effects of parent math anxiety on children's math achievement. Overall, the goal of this dissertation is to establish how a specific parent characteristic – math anxiety – influences parent involvement in their children's math learning, and to explore how we can support parents in their efforts to promote their children's academic achievement.

1.1. The Role of Parents in Education

The idea that parents play a central role in their children's education, and more broadly that the environment in which a child grows up will influence how they think and what they think about, is not new. At the beginning of the 20th century, Vygotsky's (1978) socio-cultural theory expounded on the importance of a child's social environment for his/her cognitive development. According to this theory, cognitive development occurs through social interactions between two partners – a more experienced partner (the mentor, e.g. a parent or teacher) and a less experienced partner (i.e. the child). He reasoned that children are best able to learn when the adults around them can facilitate problem solving within what he termed the “zone of proximal development” (where the child cannot yet solve a problem independently but is capable of doing so with a more knowledgeable partner's guidance). To provide effective scaffolding for these interactions, adults need to be sensitive to the child's level of competence, and as their children's primary caregivers, parents are uniquely situated to have the deepest understanding of their child's abilities.

Similarly, Bronfenbrenner's (1979) bioecological systems theory highlights the importance of the link between the home and school environments in fostering cognitive development. In his theory, Bronfenbrenner describes how each individual exists within a series of expanding systems. Immediately surrounding an individual are microsystems, which represent activities or relations that occur in a defined setting, and where the individual interacts directly with others (e.g. parents, teachers, peers, etc.). Mesosystems then represent the interconnections between two or more microsystems (e.g. the parent-teacher relationship). These have an indirect impact on an individual through his/her interactions within the microsystems. The micro- and meso-systems are then surrounded, in turn, by exosystems (indirectly impact the individual through influences on the micro- and meso-systems, e.g. education policy), macrosystems (the norms and values of cultures and subcultures), and chronosystems (historical changes that affect the individual and all other systems over time). While the child is influenced by these proximal and distal systems, microsystems, i.e., a child's direct interactions with parents and teachers, remain at the heart of development.

According to these theories, parents are critical to children's cognitive development both before and during the school years. Not surprisingly then, the relation between parent engagement and school readiness and performance is the focus of much research. Indeed, at all ages, researchers have found that various forms of parent engagement in children's education are positively associated with better outcomes.

1.1.1. Parents as Children's Primary Teachers

While research on parent involvement in education typically focuses on involvement following the advent of formal schooling, children do not exist in a vacuum prior to starting school, and so it should come as no surprise that parent input during the first years of a child's

life is also of paramount importance. Research examining children's early experiences has found that parent input prior to school is important for children's language development, later literacy skills, vocabulary growth and strengthening the processing skills that facilitate language growth (e.g. Anders et al, 2012; Duursma, Augustyn, & Zuckerman, 2008; Huntsinger, Jose & Luo, 2016; Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002; Reynolds & Temple, 1998; Weisleder and Fernald, 2013).

Yet, while we know that parent input is important for children's language and literacy learning, less attention is paid to the importance of early math input for the development of children's math skills. Parents often mistakenly believe that reading and social skills are more important for their preschool-aged children to learn than math (Galper, Wigfield and Seefeldt, 1997; Musun-Miller and Blevins-Knabe, 1998; Tudge and Doucet, 2004) and that math instruction is best left in the hands of teachers (Cannon and Ginsburg, 2008). And, increasingly, pressure is placed on schools and teachers to improve the math performance of students, ignoring the fact that parents are also teachers of their children. While a significant source of early number input may in fact be from daycares and preschools (Klibanoff, et al., 2006), parental math input plays a critical role in the development of children's mathematical knowledge (e.g. Bhanot & Jovanovic, 2005; Gunderson & Levine, 2011; Levine, Gunderson, & Huttenlocher, 2010). Understanding the role of early math input and assisting parents and caregivers in providing math input to children that is both quantitatively and qualitatively rich is an important focus in efforts to close the math knowledge gap that emerges even before children enter kindergarten.

Thus, in recent years, researchers have started to explore the role of parent input on children's early math learning, focusing on the types and frequencies of math-related activities

parents engage in with their children (Casey et al., 2018; LeFevre et al., 2009; Levine, Suriyakham, Rowe, Huttenlocher, & Gunderson, 2010; Manolitsis, Georgiou, & Tziraki, 2013; Niklas & Schneider, 2014; Ramani, Rowe, Eason, & Leech, 2015; Skwarchuk, Sowinski, & LeFevre, 2014; Susperreguy & Davis-Kean, 2016). Much of this work has found that differences in the amount of early exposure to math relates to children's early understanding of basic number concepts, such as the cardinal principle, as well as later performance in school. For example, Levine et al. (2010) found that parent number talk during naturalistic observations between the ages of 14 to 30 months predicted children's number knowledge at the age of 46 months. Furthermore, using data from the NICHD Early Child Care Research Network, Casey et al. (2018) found that mothers' number talk during an observational study when children were 36 months old, predicted children's performance on the Woodcock-Johnson (WJ) Applied Problems Subtest at age 4.5 and in 1st grade.

Given these findings, it might seem obvious to conclude that simply increasing parent number talk in the home would lead to better outcomes for children's preparedness for math when entering school. However, research has also shown that not all math interactions are created equally, and indeed the variability in the quality of parent math input, and not just the quantity, is related to child outcomes as well (Casey et al., 2018; Gunderson & Levine, 2011; Huntsinger, Jose, Larson, Balsink Krieg, & Shaligram, 2000; LeFevre et al., 2009; Ramani et al., 2015; Saxe, Guberman, & Gearhart, 1987; Skwarchuck, 2009). Therefore, understanding the sources of variation in both the quantity and quality parent early math talk are an important first step in developing interventions to improve children's math readiness at school entry.

1.1.2. Parent Involvement During the School Years

Once children start school, parents are still responsible for fostering their children's academic achievement. Indeed, in Bronfenbrenner's framework, the parent-teacher relationship is one of the primary mesosystems influencing a child's development and is especially critical in early childhood during the transition from home to preschool and kindergarten. Over the decades, multiple frameworks for understanding the types of supports that parents provide for their children have been described by researchers over the years (e.g., Eccles & Harold, 1993; Epstein, 1987, 1995; Hoover-Dempsey & Sandler, 1995, 1997; Pomerantz, Moorman, & Litwack, 2007; Grolnick & Slowiaczek, 1994). However, there seems to be a growing consensus for categorizing parent involvement along the distinct lines of those activities that maintain a direct connection between the home and school (e.g., homework help), home activities that supplement school learning (e.g., family trips to a museum), and academic socialization, which relates to the attitudes and expectations that parents have about school and education that may convey the value and utility of education and support children's own educational aspirations.

Research on the effects of parent involvement in education has primarily focused on the general student population, finding that parent involvement has a positive influence on educational outcomes for both reading and math (Crane, 1996; Fan & Chen, 2001; Jeynes, 2005; Shaver & Walls, 1998). For example, parents' support of math learning at home, either by discussing homework, or utilizing other materials to engage with their children around math, is related to increases in student math achievement (Sheldon & Epstein, 2005). More recently, researchers have started to parse apart the specific aspects of parent involvement that have beneficial impacts on learning outcomes. Hill and Tyson (2009) explored parent involvement along the lines of school- and home-based involvement, as well as what they termed "academic

socialization.” While they found no effects of school-based involvement (most closely aligned with the category of behavioral involvement outlined above) and only moderate effects of home-based (or, cognitive-intellectual) involvement, the strongest effects were related to academic socialization, through which parents convey the value of learning and explain how children’s interests connect to what they are learning, etc. Similarly, McWayne et al., (2004) found that talking to children about school activities was related to reading and math achievement, while direct involvement with schools (e.g. attending parent meetings) was not. As such, research seems to most consistently support the link between activities that fall under the umbrella of academic socialization with later academic achievement (Eastman, 1988; Grolnick & Slowiaczek, 1994; Hill & Taylor, 2004; Marchant, Paulson, & Rothlisberg, 2001; McWayne, Hampton, Fantuzzo, Cohen, Sekino, 2004; Seginer, 1983; Topor, Keane, Shelton, & Calkins, 2010; Weiss, Bouffard, Bridglall, & Gordon, 2009), and the same holds true specifically in the domain of math (DeFlorio & Beliakoff, 2015; Kleemans, Peeters, Segers, & Verhoeven, 2012). This suggests that parent involvement is particularly important because of the expectations and values for educational achievement that are conveyed to children through a parent’s actions, and in fact the expectations of other important adults in children’s lives, such as their teachers, have also proven to be important predictors of student achievement (e.g., Rosenthal & Jacobson, 1968; Rubie-Davies, Hattie, & Hamilton, 2010).

On top of parents’ expectations and values about math relating to student achievement, it is clear that other aspects of parents’ attitudes towards math are also related to students’ long-term math outcomes. Skwarchuck et al. (2014) showed that parents’ reported enjoyment of math is related to children’s non-symbolic arithmetic ability. Additionally, frequently expressing negative attitudes towards math (e.g. “I am not good at math”) is related to children’s decreased

interest and lower achievement in math (Hyde et al., 2016). The negative attitudes that adults hold towards math may tie into their low expectations for their children in math or lead them to fail to impart the value of math in everyday life to their children. This, in turn, may lead to children having lower motivation and achievement in math (Harackiewicz, Smith, & Priniski, 2016; Rozek et al., 2017). Taken together, these studies suggest that children may pick up on their parents' attitudes and beliefs about math, and when parents model positive attitudes about math, they have children who are more likely to adopt and act on those values on their own (Simpkins, Fredricks & Eccles, 2012).

1.1.3. Factors Leading to Variation in Parent Involvement

The research highlighted above emphasizes the importance of parent input for preschool children's early number development and of continued parent involvement during the school years for children's math achievement. However, this body of work also demonstrates that variation in parent input leads to differences in children's math knowledge. Therefore, it is important to understand the factors that lead to variation in the quantity and quality of parent-child math interactions during both the ages when children are spending most of their time at home, through the transition into preschool, kindergarten and early elementary school.

Previous work has started to address the cause of the gaps in early parent input, and has found that differences in parents' math engagement and number talk with their young children are related to background factors such as socioeconomic status (SES; DeFlorio & Beliakoff, 2015; Jordan, Levine, & Huttenlocher, 1994; 2006; Saxe et al., 1987; Starkey, et al., 1999; Stipek, Milburn, Clements, & Daniels, 1992; Vandermaas-Peeler, Nelson, Bumpass, & Sassine, 2009), as well as parents' own math abilities such as their approximate numerical acuity and history of math disabilities (i.e. dyscalculia; Elliot, Braham, and Libertus, 2017; Niklas &

Schneider, 2014). Furthermore, there continue to be documented SES-based differences in parent involvement even after children enter school, and more specifically in the expectations and values that parents hold for their children's future success in school (e.g., Lee & Bowen, 2006).

The reasons that parents choose to get involved in their children's education can also help us understand the observed variation in parent engagement (e.g., Grolnick, 2016; Hoover-Dempsey, et al., 2001). If parents are pushed into assisting their children, their involvement might temporarily increase, but is rarely sustained (Grolnick, 2016). Furthermore, parents who feel forced to help their children with homework are more likely to be unhappy while doing so, which can translate into a negative interaction for the child. Indeed, this may help explain why parent involvement interventions tend to have mixed results (Gorard & Huat See, 2013).

Finally, yet another source of this variation in parent math engagement comes from a parent's sense of efficacy as it relates to feeling competent in their ability to assist their children with homework and, more specifically, math learning (e.g., Hoover-Dempsey & Sandler, 1995, 1997). Importantly, parents' math self-efficacy has been linked to parents' own negative feelings about math, expressed in the form of math anxiety (e.g., Cooper & Robinson, 1991; Meece, Wigfield & Eccles, 1990). Given the importance of parents' expectations and values for their children in math, as well as their early math input prior to formal schooling, it is crucial to develop a deeper understanding of how parents' emotional experiences of math might influence parent-child math interactions and student math outcomes. In other words, what are the intergenerational effects of parents' attitudes toward math and children's math outcomes?

1.2. What is Math Anxiety?

Many people have an irrational, emotional response to the thought of dealing with numbers (Suárez-Pellicioni, Núñez-Peña, & Colomé, 2016). This math anxiety – the fear and

apprehension a person feels around doing math (Ashcraft, 2002; Ashcraft & Faust, 1994; Hembree, 1990; Richardson & Suinn, 1972) – is not only aroused in academic settings, such as taking a math test, but also 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 is estimated to be high math anxious (Eden, Heine & Jacobs, 2013). Other estimates put the number of people experiencing math anxiety in the U.S. even higher – approximately one-quarter of 4-year college students and nearly half of community college students report experiencing a moderate to high degree of math anxiety (Dowker, Sarkar, & Looi, 2016; Sprute and Beilock, 2016).

Math anxiety is not only about complex mathematics – it is evident in children as early as first grade (e.g. Harari, Vukovic & Bailey, 2013; Ramirez, Gunderson, Levine & Beilock, 2013; Wu, Barth, Amin, Malcarne, Menon, 2012), increases across schooling (Dowker, Sarkar, & Yen Looi, 2016; Hembree, 1990) and is linked to poor performance in math (Ho et al., 2000; Ma & Kishor, 1997). While it is possible that math anxiety leads to lower math performance, research also points to low math knowledge being causally linked to math anxiety, suggesting a bidirectional relationship (Beilock, Schaeffer, & Rozek, 2017; Gunderson, Park, Maloney, Beilock, & Levine, 2018; Núñez-Peña & Suárez-Pellicioni, 2014). Research also suggests that math anxiety is related to difficulties not only with complex math encountered during schooling, but also with basic number skills, such as being less accurate at identifying the number of items presented in an array (Ashcraft & Faust, 1994; Maloney, Risko, Ansari, & Fugelsang, 2010; but for contrasting findings, see Dietrich, Huber, Moeller, & Klein, 2015).

1.2.1. Effects of Math Anxiety on the Individual

Math anxiety exists across the spectrum of math achievement (e.g., Foley et al., 2017), and while it is related to poor performance in mathematics, math anxiety is not a proxy for poor math ability (Faust, Ashcraft, & Fleck, 1996; Jamieson, Peters, Greenwood & Altose, 2016; Park, Ramirez, & Beilock, 2014). For example, laboratory manipulations of pressure can lead to lower math performance (e.g. Ashcraft & Kirk, 2001; Ramirez & Beilock, 2011). In one study, participants in a high-pressure condition were told that their performance on a math task was linked to a monetary reward for both themselves and an unknown partner. Participants were then given 10 minutes to sit quietly (control) or to engage in an expressive writing intervention before beginning the math task. Those participants who were in the control group performed worse on the math task than the participants in the intervention group, suggesting that manipulations of pressure and anxiety can lead to poor performance (Ramirez & Beilock, 2011). Similarly, affective interventions can boost math achievement for math anxious individuals, even without teaching individuals any additional math (e.g. Park, Ramirez & Beilock, 2014). Allowing math anxious individuals to write about their worries before completing a math task lead to improved performance for those high-math-anxious individuals (Park, Ramirez, & Beilock, 2014).

One prominent theory about the relationship between math anxiety and math performance is that the fears and negative emotions that math anxious individuals experience in math-related situations use up cognitive resources, such as working memory, that might otherwise be focused on the math tasks, leading to poor performance (Beilock & Carr, 2005; Beilock, Schaeffer & Rozek, 2017). Working memory (WM) resources allow individuals to keep track of short-term information and may be particularly necessary when it comes to solving math questions to hold intermediate steps in mind and compute solutions (Park, Ramirez & Beilock,

2014). Counter-intuitively, the negative effects of math anxiety are greatest in individuals with high WM, and this math anxiety x working memory interaction holds around the world (Foley et al., 2017). What accounts for this interaction? Evidence suggests that worries deplete WM capacity and compromise the ability of high working memory individuals to employ more WM intensive, efficient strategies that they would otherwise utilize (e.g. Ashcraft & Kirk, 2001; Park, Ramirez & Beilock, 2014). For example, Beilock and Carr (2005) tested adults who were high and low in WM on a math task and manipulated whether they were solving problems in a high- or low-pressure situation. They found that high-WM individuals showed performance deficits only on those problems that made the largest demands on their WM. In contrast, while low-WM individuals performed less well on those same high-demand problems even in the absence of pressure, their performance did not decline further when placed under pressure. These effects are also evident by early elementary school as shown by a study which found that 1st and 2nd graders who were high in WM performed more poorly than their high WM peers who were not math anxious on calculation problems (Ramirez, Gunderson, Levine & Beilock, 2013). This was 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 WM-High Math Anxiety students deployed the more basic strategies used by low working memory students (e.g., counting) regardless of whether they were high or low math anxious (Ramirez, Chang, Maloney, Levine, & Beilock, 2016). Taken together, these findings show that math anxiety can compromise the potential of high working memory individuals to perform at high levels in math. At the same time, when individuals underperform in math, this may increase their anxiety (Gunderson et al., 2018; Levine, Gunderson, Maloney, Ramirez & Beilock, 2015; Foley et al., 2017). Thus, math anxiety prevents individuals from demonstrating their true ability

through a vicious cycle in which anxiety leads to poor performance and the poor math performance leads to increased anxiety.

In addition to not being solely a proxy for poor math ability, math anxiety is also not only related to performance on more complex math problems; there is also some evidence that math anxious individuals may approach even simple arithmetic problems differently than low math anxious individuals. Chang and colleagues (Chang, Sprute, Maloney, Beilock & Berman, 2017) explored the neural correlates of simple arithmetic problems using functional magnetic resonance imaging across both high- and low-math anxious individuals. They found that while both low- and high-math anxious individuals performed similarly on the math task, there were still differences in the activation of their fronto-parietal network that were associated with performance on the task. When low math anxious individuals recruited this attention-related network less, their performance improved, while there was no such relation for the performance of high-math anxious individuals. These findings suggest that low and high math anxious individuals approach even the most fundamental math problems differently.

Finally, individuals who suffer from math anxiety are plagued by more than just feelings of apprehension around math; the signs of elevated cognitive and physiological arousal that individuals demonstrated when faced with math has lead researchers to argue that math anxiety is a genuine phobia (Ashcraft & Ridley, 2005; Faust 1992; Suárez-Pellicioni et al. 2016). For example, Faust (1992) found changes in math anxious individual's heart rates when faced with math tasks of increasing difficulty, but not for verbal tasks of similar difficulty. Furthermore, in an fMRI study, Lyons and Beilock (2012) demonstrated that simply thinking about math can elicit a neural pain response similar to those associated with threat detection and even the experience of pain itself.

Given the extreme nature of the feelings associated with math for individuals, it should come as no surprise that math anxiety does not only impact performance on math tasks, it also affects behavior outside of academic situations. Math anxious individuals tend to avoid situations where they might encounter math (Ashcraft, 2002; Ashcraft, Krause & Hopko, 2007; Hembree, 1990; Maloney & Beilock, 2012). They take fewer math classes than their non-math anxious counterparts, and when they do take math classes, they tend to perform worse in the class than those who are less math anxious (Ashcraft, 2002; Hembree, 1990; Ma, 1999). Math anxious individuals also avoid math-related majors and careers and may even avoid seemingly mundane activities like calculating a tip at a restaurant (Chipman, Krantz, & Silver, 1992). Math anxiety may even impact consumer behavior, with math anxious individuals preferring absolute discounts (e.g. \$5 off, \$25 regular price) to relative discounts (e.g. 20% off, \$25 regular price) even if the relative discount was higher than the absolute discount (Suri, Monroe, & Koe, 2013). Math anxious individuals also tend to have low math self-efficacy (e.g., Cooper & Robinson, 1991; Meece et al., 1990). It is likely that this lower math self-efficacy contributes to math avoidance behaviors and in fact, parents' perceived self-efficacy is one of the most significant factors in a parent's decision to get involved in their child's education (Hoover-Dempsey et al., 2001; Hoover-Dempsey et al., 2005).

1.2.2. Intergenerational Impact of Math Anxiety

While math anxiety has been shown to affect the math performance of the individuals who suffer from this anxiety, research has shown that it also can have intergenerational effects. Work from our lab has demonstrated that children who have math anxious teachers learn less math over the school year. Beilock, Gunderson, Ramirez and Levine (2010) found that female students in classrooms with highly math anxious teachers performed worse in mathematics than

their female student peers in classrooms without math anxious teachers at the end of the year and were more likely to endorse negative gender stereotypes about mathematics. In this study, Beilock et al. assessed the math anxiety of 17 first- and second-grade female teachers, and then looked at the math achievement and beliefs about math of the 117 students in their classrooms. While there was no relation between students' math achievement and their teachers' level of math anxiety at the beginning of the year, female students' math achievement was negatively correlated with teachers' math anxiety at the end of the year, though the same was not true for male students. This relation was mediated by girls' gender ability beliefs – female students with math anxious teachers came to have relatively increased acceptance of traditional gender norms in school (i.e. girls are better at reading, boys are better at math), which in turn impacted their math performance. Indeed, other research has shown that teacher efficacy is negatively related to their math anxiety, suggesting that math anxiety might undermine teachers' confidence in their ability to teach math to their students (though it may also be the case that low confidence in mathematics abilities leads to higher levels of math anxiety) (Bursal & Paznokas, 2006; Swars, Daane & Giesen, 2006).

And it's not only teachers who are impacting students' lives. Parents' math anxiety matters for student achievement, too (e.g., Casad, Hale, & Wachs, 2015; Eason, Nelson, Dearing, & Levine, under review; Maloney et al., 2015). While 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 fact, when math anxious parents provide more frequent math homework help to their 1st and 2nd graders their children learn less math over the school year 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 holds controlling for

children's math 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 if it is low in quality. Similarly, a study conducted in India reports that parents' math anxiety is a significant positive predictor of adolescents' math anxiety and math attitudes in high school, and that adolescents' anxiety and attitudes are negatively associated with their math achievement (Soni & Kumari, 2015). Furthermore, when parents are math anxious, they provide lower levels of number talk to their preschool children, particularly the kinds of number talk that may be most important in driving learning, such as providing prompts to talk about number (e.g., asking a child questions like "How many?", or "Can you count the blocks?", etc.) (Eason et al., under review). Together, these studies suggest that math anxiety could be leading to differences in both the quantity and quality of teacher-student and parent-child math interactions and implicate these differences in children's math learning.

1.3. Research Question

Understanding the role of early math input on children's academic achievement and assisting parents and caregivers in providing early math input to children that is both quantitatively and qualitatively rich may help close the math knowledge gap that emerges even before children enter kindergarten. The present thesis aims to explore how a specific barrier to parent math engagement influences parent-child interactions, looking at parent math engagement through a variety of lenses.

First, in Study 1, using data from a naturalistic observation, I look at whether parent math anxiety impacts even the earliest parent-child interactions that occur in the home environment. In Study 2, I then explore how parent math anxiety relates to parent involvement, defined both in terms of the math-related activities they engage in with their children as well as their

expectations and values for their children in math as they enter school. Furthermore, I connect survey data on parent involvement to an in-lab observation of parent-child interactions, designed to afford but not require number talk. Finally, in Study 3 I ask whether we can develop interventions that support students with math anxious parents, who are likely receiving lower quality math input at home and whose parents likely hold lower expectations for them in math, in their math learning at school. While parent math input is impacted by a variety of factors, interventions aimed at improving parent-child math interactions will be most successful if developed in conjunction with the cultivation of a deeper understanding of the obstacles parents face in engaging their children in math learning.

2. CHAPTER TWO Study 1: Parent Math Anxiety Predicts Early Number Talk

2.1. Background

The skills and knowledge that children bring with them to kindergarten are important predictors of early achievement (Alexander & Entwisle, 1988; Claessens, Duncan & Engel, 2009; Jordan, Kaplan, Ramineni, & Locuniak, 2009), highlighting the importance of the experiences children have at home during the first five years of life. Research examining children's early experiences shows that variations in children's language input has an impact on their language development and later literacy skills (e.g. Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002; Reynolds & Temple, 1998). For example, early language input is related to variations in children's vocabulary growth and is responsible for strengthening the processing skills that facilitate language growth (e.g. Weisleder & Fernald, 2013). Similarly, reading out loud with children facilitates children's language development and literacy skills (Duursma, Augustyn, & Zuckerman, 2008). Moreover, the richness of parental vocabulary and the overall quantity of parent talk is related to differences in children's vocabulary growth both within and between SES groups (e.g., Hart & Risley, 2003; Huttenlocher, Haight, Bryk, Seltzer, & Lyons, 1991; Rowe & Goldin-Meadow, 2009; Huttenlocher, Waterfall, Vasilyeva, Vevea & Hedges, 2010). Based on these findings, intervention efforts often focus on encouraging parents to talk more to their children and engage them in literacy related activities.

More recently, research has turned to the role of parents' math input on their children's math development and later math skills (e.g., Blevins-Knabe & Musin-Miller, 1996; Levine, Gunderson, & Huttenlocher, 2011; Gunderson & Levine, 2011). Children show wide variation in their understanding of basic numerical concepts upon entering kindergarten (e.g., Starkey, Klein, & Wakely, 2004; Starkey & Klein, 2008); and these differences persist throughout schooling

(e.g., Duncan et al., 2007; Romano, Babchishin, Pagani, & Kohen, 2010). Unsurprisingly, these differences in math knowledge at school entry are related to variations in parents' early math input at home (Blevins-Knabe & Musin-Miller, 1996; LeFevre, Clarke, & Stringer, 2002; Saxe, Guberman, & Gearhart, 1987). Previous research has revealed a great deal about the developmental trajectories through which children develop an understanding of fundamental math concepts (e.g., Sarnecka & Carey, 2008; Wynn, 1990, 1992), and this body of work has led some researchers to highlight the role of language in the development of number concepts, implicating parents' early number talk as a fundamental component of children's early math development.

2.1.1. The Role of Language in the Development of Math Concepts

Infants are born possessing remarkable abilities to perceive and reason about the world around them, including several precursors to formal mathematics. Researchers have argued that we are born with two innate core number systems – the object tracking system and the approximate number system (e.g., Carey, 2004, 2009; Feigenson, Dehaene, & Spelke, 2004; Le Corre et al., 2006). The object tracking system (OTS) is a small, exact number system that enables us to track a limited number of objects, but has a clear set size limit. Using the OTS, individuals can index objects and discriminate between small sets (e.g., 3 versus 2) but this system fails to track larger sets (i.e. 4 and up) because it lacks a summary symbol, such as a number word, for set size. The upper limit of this system has been demonstrated by multiple studies, showing that infants reliably track up to 3 objects but fall apart when asked to track more (Feigenson, Carey & Hauser, 2002; Feigenson & Carey, 2003, 2005). For example, in one study infants saw crackers sequentially hidden in two buckets, and they reliably chose the bucket with the larger quantity when asked to choose between sets of 1 versus 2 and 2 versus 3 crackers.

However, when a larger set (i.e. 4 or 6) was one of the options, infants failed to reliably choose the larger quantity, despite a highly discriminable ratio between the arrays (Feigenson, Carey, & Hauser, 2002). Furthermore, the limit of the OTS in infants is similar to the limit exhibited by adults, suggesting that the same representations underlie infants' and adults' tracking of small numbers of individuals (Carey & Xu, 2001; Feigenson, Carey, & Hauser, 2002)

In contrast to the OTS, the approximate number system (ANS) provides a summary representation of set size, but this representation is approximate and becomes less accurate with increasing set size, in accord with Weber's Law (e.g., Dehaene, 1997; Gallistel & Gelman, 2000; Xu & Spelke, 2000). Thus, while the system can differentiate 2 versus 3, it cannot consistently differentiate larger sets that are close in magnitude (e.g., 15 versus 16). Evidence for the limits of this system come from studies demonstrating that infants' large number discrimination follows defined ratio limits (e.g., Xu & Spelke, 2000; Feigenson, Dehaene, & Spelke, 2004). For example, 6-month-old infants can discriminate between sets of 8 versus 16 dots, or 16 versus 32 dots (1:2 ratio) but not 8 versus 12 or 16 versus 24 (2:3 ratio; Feigenson, Dehaene, & Spelke, 2004), and can even perform approximate operations such as addition and subtraction on large, approximate sets (McCrink & Wynn, 2004).

While all children possess these core number skills to some extent, children have a great deal of difficulty learning the meanings of number words ("one," "two," "three," etc.), and indeed these seemingly fundamental concepts are not universal. So, how do children shift from relying on their core number systems to developing more advanced, exact concepts of number? Researchers have suggested that language, and experience with a verbal counting system, is a facilitator of the development of more advanced number concepts (Carey, 2001; Frank, Everett, Dedorenk, & Gibson, 2008; Gelman, 1991; Pica, Lemer, Izard, & Dehaen, 2004; Spaepen,

Coppola, Spelke, Carey, & Goldin-Meadow, 2011; Spelke & Tsivkin, 2001). Evidence for the role of language comes from examples of people who speak languages with few number words, and who have no counting system (e.g., the Mundurukú or Pirahã in Brazil, or deaf individuals who lack access to signed or spoken language). These individuals never develop an understanding of large, exact quantities such as ‘exactly 32,’ and instead continue to treat numbers as approximate. For example, studies with the Mundurukú tribe have demonstrated that they are very accurate when asked for small numbers of objects (e.g., 1 and 2) but with larger numbers (e.g., 9) they tend to respond by saying things like “some, not many” or “many, really many” (Pica et al., 2004). Furthermore, while they can perform operations on sets of large numbers, which they represent approximately, they cannot perform exact operations on set sizes that are beyond 3 or 4 (Pica et al., 2004).

Similarly, adult homesigners in Nicaragua provide another striking example for the role of language in the development of number concepts. These deaf individuals have lived in a numerate society but have no formal language for representing numbers. When asked to look at a picture with sets of objects (set sizes 1 to 30) and describe how many objects were on the card, or to match the number of knocks an experimenter made on their fists, adult homesigners were able to accurately represent smaller numbers (i.e. 1- 4) but their responses became more approximate with larger numbers (Spaepen, Coppola, Spelke, Carey, & Goldin-Meadow, 2011).

Further evidence for the role of language in children’s development of number concepts can be found from children who have delayed access to language. Children who are born deaf or hard-of-hearing (DHH), and then receive cochlear implants between the ages of 1- to 2-years, provide an excellent example of how delayed access to language relates to an understanding of exact number (Shusterman, Berkowitz, & Lange, 2012). On a non-verbal number task, when

DHH preschoolers were asked to approximate numbers, they performed the same as their hearing-peers. However, on a more exact number task, the DHH children showed delays in their understanding of number that related to the amount of time that had elapsed since their successful hearing intervention. This suggests that more advanced number knowledge develops in conjunction with consistent exposure to language (Shusterman, Berkowitz, & Lange, 2012).

2.1.2. Parent Number Language and Early Math Development

Given the importance of language in the development of advanced number concepts, it is not surprising that the math-related language input parents provide to their children relates to their number knowledge. Variations in the age at which children learn fundamental concepts, such as the cardinal principle (the idea that the last number in a count list refers to the size of the whole set), as well as their later math knowledge, is related to variation in language input (Blevins-Knabe & Musun-Miller, 1996; Chang, Sandhoffer, Adelchanow, & Rottman, 2011; Durkin et al., 1986; Klibanoff et al., 2006; LeFevre, Clarke, & Stringer, 2002; Levine et al., 2010; Sarnecka et al., 2007; Susperreguy & Davis-Kean, 2016). In one study, Levine et al. (2010) found large differences in the amount of number talk that parents engaged in with their children that related to later number knowledge. They videotaped natural interactions of 44 parent-child dyads in their homes, visiting every 4 months beginning at the age of 14 months. In their videos, Levine et al. (2010) found that the number input children received between 14 and 30 months ranged from a low of 4 number words to a high of 257 number words in a single session. This variation in number input was related to children's own talk about numbers and their later understanding of the cardinal values of number words, even when controlling for overall parent talk to the child and socioeconomic status (SES), suggesting that it was specifically talk about numbers, and not talk in general, that is connected to later number

knowledge. Importantly, recent research has found that the age at which children gain an understanding of the cardinal principle predicts their later math skills, further underscoring the importance of early input and a focus on cardinality (Geary et al., 2018). Additionally, kindergarten children's scores on the Test of Early Mathematics Ability – Second Edition (TEMA-2; Ginsburg & Baroody, 1990) were correlated with parents reported frequency of using the number words “one,” “two,” and “three,” or of mentioning simple number facts (Blevins-Knabe & Musun-Miller, 1996), again underscoring the importance of parents' number talk in the development of math knowledge.

And, it is not just the quantity of parent input that matters – more recent research suggests that the quality of parent input varies and relates to children's number knowledge as well (e.g., Casey et al., 2018; Gunderson & Levine, 2011; Ramani, Rowe, Eason, & Leach, 2015). In a follow-up to the Levine et al. (2010) study, Gunderson and Levine (2011) found that specific types of number talk were more predictive of later number knowledge than others. For example, number talk that included counting or labeling of present sets of larger objects (i.e. 4-10) was more predictive of performance on the Point-to-X task than rote counting or use of smaller number words. The idea that talk about larger numbers may be more beneficial is supported by subsequent research suggesting number talk when children were 5- to 6-years-old was predictive of children's math ability only when it included talk about numbers larger than 10 (Elliot et al., 2017). However, it is perhaps the case that the number input that predicts later math milestones depends on the number knowledge level of the child at the time the input is assessed.

Casey et al. (2018) also found that parents' labeling of cardinal number sets (but not one-to-one-counting or labeling numerals) when the children were 36 months old, predicted children's performance on a math assessment when the children were 4.5 years old and in 1st

grade. Furthermore, Ramani et al. (2015) categorized parents' number talk as either "foundational" (e.g., counting and numeral identification) or "advanced" (e.g., cardinality, arithmetic, and ordinal relations) and found that it was specifically talk about the more advanced number concepts that related to ability on various number tasks. Together, these findings suggest that number talk that includes cardinal labeling of sets, talk about larger set sizes, and talk about present objects may be important contributors to young children's acquisition of number concepts, and therefore constitute higher quality math talk.

2.1.3. Parent Characteristics Associated with Variation in Math Talk

What are the factors that contribute to variation in the quantity and quality of parent's early math talk? Despite the relation of variation in parent input to differences in children's early math knowledge, little is known about the factors that impact parent input during the years prior to the start of formal schooling. We do know that starting as early as the age of 3, there are large SES-based differences in children's mathematical knowledge across multiple domains (Clements & Sarama, 2007; Jordan, Huttenlocher, & Levine, 1992; Jordan & Levine, 2009; Starkey, Klein, & Wakeley, 2004; Starkey & Klein, 2008; Verdine et al., 2014). Even if children then participate in school readiness programs, these differences persist, so that by kindergarten, children from low-SES households are already one developmental year behind children from higher-SES families in mathematics (Hughes, 1986; Starkey et al., 2004).

Researchers have found that in general, levels of parental involvement are lower among low-SES families (e.g., Abrams & Gibbs; 2002, Epstein, 1995). Therefore, these SES-based gaps in math knowledge may stem from SES-based differences in parents' home numeracy practices. In support of this idea, Starkey et al. (1999) asked parents to indicate how often they typically engaged their children in various activities at home. All of the activities presented to parents

were those that would typically be used to support early math development. They found that middle-SES parents reported engaging their children in more types of math-related activities (e.g. made-up games involving math and reading number or shape books) and provided more support for these activities. Middle-SES mothers also report incorporating math into their daily routines more frequently than their lower-SES counterparts (Stipek, Milburn, Clements, & Daniels, 1992). Interestingly, in another study, which asked parents about the math activities they engaged in with their children, no reported differences between SES groups were found for the range and frequency of activities (Saxe et al., 1987). Rather, higher-SES parents reported engaging their children in more complex mathematical activities than low-SES mothers, and these differences then correlated with children's performance on more complex mathematical problems.

Beyond looking at children's SES backgrounds, researchers have found support for other factors that influence variation in parent math engagement, such as parents' beliefs about their own abilities in math, as well as their attitudes towards math and their expectations for their children in math (Barbarin, et al., 2008; Elliott, Braham, & Libertus, 2017; LeFevre, Polyzoi, et al., 2010; Missall, Hojnoski, Caskie, & Repasky, 2015). For example, in addition to SES predicting parent home numeracy engagement, Starkey et al. (1999) found that SES related both to differences in parents' beliefs about the importance of the home (versus school) environment on children's math development, and expectations parents had for their children's math abilities at the end of preschool.

DeFlorio and Beliakoff (2015) similarly found that while SES related to the frequency and range of math activities children participated in at home, middle-SES parents also held higher expectations for their children in math, as compared to lower-SES parents. Furthermore,

they found that parents' expectations and knowledge of early math development contributed unique variance to children's performance on a math assessment, above and beyond SES (DeFlorio & Beliakoff, 2015). Similarly, Kleemans et al. (2012) found that parents' expectations for their children's academic success in math are related to their children's achievement in math. Parents' beliefs and attitudes about their children's academic success may be of particular importance because they predict parents' own behaviors, including their overall level of engagement in their children's education (e.g., McGillicuddy-DeLisi & Sigel, 2002).

Perhaps, then, an additional factor impacting the frequency of parents' talk to their children about math are the negative feelings parents experience that lead to math avoidance. As reviewed in Chapter 1, a potential avenue that is ripe for further exploration is the role of parents' math anxiety on their tendency to engage their children in math-related activities, since math anxious individuals avoid math in a variety of contexts. Furthermore, there is some evidence that math anxious teachers have lower expectations for their students' success in math (Mizala, Martinez, & Martinez, 2015), suggesting that math anxious parents may similarly hold low expectations for their children's math achievement. While there is some work linking adults' math anxiety to older children's math achievement (Beilock, Gunderson, Ramirez, & Levine, 2010; Casad, Hale, & Wachs, 2015; Maloney et al., 2015), math anxiety has not yet been systematically explored as a factor impacting the variation in the earliest form of math input, parents' number talk with their 1- to 3-year-old children (for one recent exception with 2- to 4-year-old children see Eason et al., under review). Given the importance of early number talk for the development of children's early mathematical knowledge, understanding the factors that lead to variation in parent math talk, notably parents' attitudes towards math, is incredibly important.

Here, using the same parent-child dyads that participated in the Levine et al. (2010) longitudinal study, we explore how parent math anxiety relates to observed variation in parent math talk.

2.1.4 The Present Study

The present study aims to answer two main questions. First, how does parent math anxiety relate to the quantity of parent number talk? Do parents who are anxious about math talk less to their children about number, even when their children are very young (i.e., under age 3), when presumably math talk tends to be very simple? Second, we ask how parent math anxiety relates to the quality of parent number talk that is occurring in the home. Even if highly math anxious parents are engaging their children in number talk, the type of number talk they use may not foster children's acquisition of number concepts.

To test these questions, we observed 36 parent-child dyads in their homes in five 90-minute sessions when children were between the ages of 14 – 30 months. All families were part of a larger longitudinal study on language development, and so at a later time point, parents were given a survey to measure their math anxiety.

Parent number talk over the course of the recorded sessions was coded for instances of number talk. Number talk was further categorized according to its context – whether it included counting or cardinal labeling of set sizes, the size of the sets being discussed and whether objects were present or not. These distinctions were made based on findings from previous studies demonstrating that some types of number talk may be qualitatively better than others.

We hypothesize that parents' math anxiety will predict less overall math talk in the home when children are under the age of 30 months. We also expect to find that parent math anxiety relates to use of 'higher' quality number talk (i.e., cardinal labeling, talk about present objects and talk about larger numbers) but not use of "lower" quality number talk. As reviewed above,

previous research has found that cardinal number talk is a better predictor of children's later understanding of foundational mathematical concepts, such as the cardinal principle, than is counting (Casey et al., 2018). This suggests that cardinal number talk is a higher quality type of number talk than counting, and we therefore anticipate that high math anxious parents will be less likely to engage in cardinal labeling of set sizes but will not vary in their use of counting. Additionally, Gunderson & Levine (2011) found that use of large number sets (4-10) (versus smaller sets) and talk about present objects (versus without present objects) were more predictive of children's math knowledge. Therefore, we hypothesize that math anxiety will relate to parents' incorporation of these specific elements into their number talk, thereby providing lower quality math input to their children.

2.2. Method

Participants

Thirty-six parent-child (15 girls) dyads participated in this study. Dyads were taken from a larger sample of 63 families in a longitudinal study of language development that has been ongoing since 2000. Families were initially sampled through mailings and were chosen to represent the general demographics of the Chicagoland area in terms of race, ethnicity and income levels, although all children are monolingual English speakers. Children were visited every four months from the ages of 14-58 months. In the current study, we are using the data from visits between 14-30 months and dyads were included in the study only if they had data from interacting with the same caretaker for all five sessions in this range, and parents had filled out a math anxiety rating scale, leaving a sample of 36 dyads. These remaining dyads were still representative of the original sample in terms of income and education.

Procedure

Research assistants visited families at home every 4 months starting when the children were around 14 months of age and continuing until the children were 58 months of age. During these home visits, caregivers and children were videotaped for approximately 90 minutes engaging in typical daily activities, and researchers did not mention any interest in children's numerical development. Once children were 58 months of age, researchers continued to visit families' homes approximately three times a year, and when children were in middle school (~10 years old), parents were given the Short Mathematics Anxiety Rating Scale (sMARS; Alexander & Martray, 1989) to assess their feelings of fear and apprehension around math.

Coding and Reliability. The current study makes use of the number talk coding originally analyzed in Gunderson and Levine, 2011. Data is from the first five family visits (child ages 14, 18, 22, 26, and 30 months) for a total of 7.5 hours of parent-child interaction. All speech was transcribed at the utterance level, defined as any sequence of words preceded and followed by a pause, change in conversational turn, or change in intonational pattern. Dictionary words, onomatopoeic sounds (e.g. meow) and evaluative sounds (e.g. uh-oh), were counted as words. To establish transcription reliability, a second coder transcribed 20% of the videotapes. Reliability was assessed at the utterance level and was achieved when coders agreed on 95% of transcription decisions.

Measures

Parent Number Talk. Using a computer, transcripts were searched for uses of number words 'one' through 'ten'. All instances of the word 'one' were then manually coded as either numerical or non-numerical. Numerical uses of 'one' included cardinal values (e.g. 'one ball'), references to Arabic numerals (e.g. 'That's the number one'), counting (e.g. 'one, two, three') and references to time or age (e.g. 'one minute', 'when you turned one'). All other uses of 'one'

were coded as non-numerical (deictics, e.g. ‘this one’; anaphoric uses of one, e.g. ‘that’s the pretty one’; and idioms, e.g. ‘one of these days’). A second researcher coded 20% of the sessions and achieved 90% reliability (Levine et al., 2010).

Number word tokens were then coded as instances. ‘Instances’ were defined such that counting sequences would be coded as one instance of number talk, to ensure that counting sequences would not be overweighed in analyses. For example, counting ‘one, two, three’ or ‘one, two, three, four, five, six, seven’ are both considered one instance but are classified as three and seven tokens respectively (Gunderson & Levine, 2011).

Since we were also interested in exploring differences in the quality of math talk, instances of math talk were further coded according to whether parents were counting or using cardinality (labeling the number of a set), whether objects were present at the time or not, and the range of numbers being used (i.e. “small numbers” or 1-3, and “large numbers” or 4-10; Gunderson & Levine, 2011; see Table 1 for examples of types of number talk).

Table 1. Examples of types of parent number talk

Type of Talk	Example
Counting	“One, two, three, four, five.”
Cardinal labeling	“Here are three bears”
Talk about present objects	“You have two apple slices” (pointing to fruit on the table)
Talk without present objects	“Five, six shut the gate!”
Talk about small number sets	“One, two, three” (counting trucks on the floor)
Talk about large number sets	“Look! Eight legs.” (with picture of a spider)

Socioeconomic Status. Since we know that much variation in parent input is related to SES, we wanted to control for variation due to SES in our models to observe the variation that is uniquely related to parents’ math anxiety. Additionally, we hypothesized that it is possible math anxiety would have different impacts on low- versus high-SES individuals. Since lower-SES parents already tend to talk less about math, it is possible that we would be unable to detect additional variation related to math anxiety differences.

Our measure of socioeconomic status (SES) was created based on family income and the educational attainment of the primary caregiver. These variables were collected categorically on a parent questionnaire at or before the first visit and transformed into continuous scales. Mean education was 16.17 years, equivalent to a bachelor’s degree ($SD = 1.87$ years, Range = 10 [less than high school] to 18 [master’s degree or higher]), and mean income was \$62,361 ($SD = \$30,472$, Range = less than \$15,000 to over \$100,000). Income and education were positively related ($r(36) = 0.46, p = .004$) and were combined into one SES variable using Principal Components Analysis. The analysis found one component, our composite SES score, which accounted for 73% of the original variance and weighted income and education positively and equally. The composite SES score has a mean of 0 ($SD = 1$). Families with a high score on the SES composite have a high annual income and a primary caregiver with a high level of education.

Parent Math and Reading Anxiety. When children were entering high school, parent math anxiety was assessed using the sMARS (Alexander & Martray, 1989), which is a 25-item version of the widely used 98-item MARS (Suinn, 1972). Parents responded to questions about how anxious different situations would make them feel (e.g. “studying for a math test,” “calculating a tip at a restaurant,” etc.). Responses were recorded on a Likert scale from 1 (“not at all”) to 5 (“very much”). All analyses were performed on the average of the 25 items (See Appendix A for full scale). Parent math anxiety ranged from 1 to 4.2, with a mean of 2.22 ($SD = 0.91$).

Parents also completed a 25-item reading anxiety questionnaire, which was adapted from the math anxiety questionnaire (see Appendix A). Parent reading anxiety ranged from 1 to 3.4, with a mean of 1.66 ($SD = .58$).

2.3. Results

Descriptives of Parent Number Talk

We first sought to characterize the amount and types of parent number talk observed in our sample. Since parent number talk was relatively rare, we aggregated the data across the five sessions to create more stable measures of parent number talk that could be used in our models. Overall, the average of parent number talk was 67 instances ($SD = 44.41$, Range = 4 - 168). Since we also wanted to know if math anxiety predicted specific differences in parent number talk, as outlined in the Introduction, we created variables that reflected what we believed to be important qualitative distinctions in parent number talk. Our primary division of the number talk was based on Casey et al.’s (2018) finding that cardinal labeling of sets is more predictive of math knowledge than is counting and thus may be higher quality math talk. We also divided number talk into categories along the lines described in Gunderson and Levine (2011), so that we had groupings which took into consideration whether objects were present or not, and the size of

the number being used (i.e. small (1-3) and large (4-10); see Table 2 for descriptives of each category).

Table 2. Means and range of parent number talk by type

	Mean (<i>SD</i>)	Min	Max
All Number Talk	67.39 (44.41)	4	168
Cardinal	39.21 (30.09)	1	136
Counting	12.96 (12.32)	0	48
Present Objects	39.09 (29.44)	1	122
Without Present Objects	12.90 (8.67)	0	34
Small (1-3) Numbers	43.24 (29.46)	1	114
Large (4-10) Numbers	8.94 (8.04)	0	30

Relations Between Quantity of Parent Number Talk, Parent Math Anxiety and SES

We conducted a series of regression analyses to explore the relations between parents' math anxiety and the quantity of parent number talk. First, using a univariate ANCOVA (controlling for reading anxiety) we found a marginal main effect of parent math anxiety on parent overall number talk ($F(1,31) = 3.12, p = .09$) and a significant main effect of SES ($F(1,31) = 7.79, p = .009$). Additionally, we found a significant interaction between math anxiety and SES ($F(1,31) = 5.31, p = .028$); see Table 3), suggesting that parent math anxiety significantly moderates the relation between SES and parent number talk.

Table 3. Impact of parent math anxiety and SES on parent number talk

	B	SE	95 % CI	
			Lower Bound	Upper Bound
Intercept	115.89***	24.33	66.27	165.50
SES	44.72**	16.02	12.05	77.38
Parent Math Anxiety (pMA)	-13.87 ^a	7.85	-29.89	2.14
SES x pMA	-18.39*	7.98	-34.67	-2.12
Parent Reading Anxiety	-8.5	12.35	-33.69	16.69

^a $P < .10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

To further probe this SES x Parent Math Anxiety interaction, we tested the conditional effects of SES at two levels of parent math anxiety (one standard deviation above/below the mean).

Analyses revealed that SES was significantly related to parents' number talk for parents who

reported experiencing very low levels of math anxiety ($b = 22.41$, $SE = 7.81$, $p = .007$, 95% CI [6.50, 38.32]). However, SES was not related to parents' number talk for those whose math anxiety was one standard deviation above the mean ($b = -11.94$, $SE = 12.74$, $p = .36$, 95% CI [-37.89, 14.01]; see Figure 1). These results suggest that high-SES parents who experience high levels of math anxiety, look more similar to their low-SES counterparts in terms of the math talk they engage in with their children.

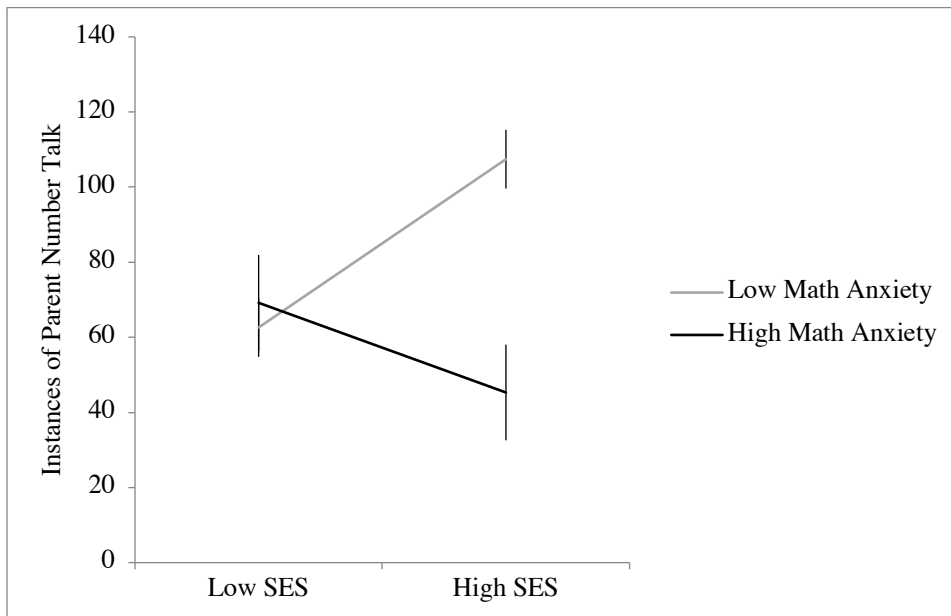


Figure 1. Relation of Parent Math Anxiety, SES and Parent Number Talk. High-SES, low-math-anxious parents provided significantly more number talk to their children than their high-math-anxious or lower-SES peers.

Relations Between Quality of Parent Number Talk, Parent Math Anxiety and SES

We next wanted to see if parents' math anxiety predicted meaningful differences in the quality of parent math talk, as defined in the Introduction. We first looked to see if parent math anxiety related to parents use of cardinality or counting in their number talk with their children. Using a multivariate ANCOVA, we found that, as in our prior model, parent math anxiety was a marginal predictor of their number talk instances ($F(2,31) = 2.87$, $p = .07$). However, math anxiety was a significant predictor of parents' use of cardinal labeling ($b = -11.44$, $p = .02$), as

was SES ($b = 36.33, p = .001$) as well as interacting with SES ($b = -13.97, p = .009$). However, neither parent math anxiety nor SES were significant predictors of parents' counting behavior with their children (see Table 4). This is in line with our hypothesis that “higher quality,” or more advanced number talk, such as talk about the cardinal value of sets, is related to math anxiety, while more basic number talk is not.

Table 4. Multivariate test of cardinal and counting number talk.

Variable	Multivariate Tests				Univariate Parameter Estimates		
	Λ	F	df ₁	df ₂	B	SE	95% CI
SES	.454	18.62**	2	31			
Cardinal Labeling					36.33***+	9.91	16.14, 56.52
Counting					3.35 ⁺	4.94	-6.71, 13.41
Math Anxiety	.844	2.87 ^a	2	31			
Cardinal Labeling					-11.44**+	4.80	-21.23, -1.66
Counting					-2.27 ⁺	2.39	-7.14, 2.60
SES x Math Anxiety	.804	3.78*	2	31			
Cardinal Labeling					-13.97**+	5.02	-24.20, -3.74
Counting					-.683 ⁺	2.50	-5.78, 4.41

^a $P < .10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

⁺ Follow-up comparisons of these parameters found that the difference between the effect of math anxiety on cardinal number talk and counting was marginally significant ($F(1,64)=2.92, p=.092$). The effects of SES and of the interaction term (math anxiety x SES) were significantly different between the two types of number talk ($F_{SES}(1,64)=8.87, p=.004$; $F_{SES*MA}(1,64)=5.60, p=.021$).

We next looked at whether math anxiety related to parents' use of small versus large set sizes in their number talk. Math anxiety was again a marginally significant predictor in the overall model ($F(2,31) = 2.76, p = .08$). In contrast to our hypothesis, we found that math anxiety predicted use of small set sizes ($b = -10.95, p = 0.03$) but only marginally predicted use of large set sizes ($b = -2.76, p = 0.07$; see Table 5).

Table 5. Multivariate test of number talk with small and large sets.

Variable	Multivariate Tests				Univariate Parameter Estimates		
	Λ	F	df ₁	df ₂	B	SE	95% CI
SES	.728	5.79**	2	31			
Small Sets					34.03***+	9.86	13.95, 54.12
Large Sets					5.65 ^{a+}	3.00	-.47, 11.76
Math Anxiety	.849	2.76 ^a	2	31			
Small Sets					-10.95*+	4.78	-20.69, -1.22
Large Sets					-2.76 ^{a+}	1.45	-5.72, .20
SES x Math Anxiety	.830	3.18 ^a	2	31			
Small Sets					-12.72*+	4.99	-22.90, -2.54
Large Sets					-1.93 ⁺	1.52	-5.03, 1.17

^a $P < .10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$ + Follow-up comparisons: $F_{pMA}(1,64)=2.69, p=.11$; $F_{SES}(1,64)=7.58, p=.008$; $F_{SES*pMA}(1,64)=4.27, p=.04$.

Last, we compared whether parents' math anxiety related to their tendency to talk about sets of present versus absent objects. Once again, math anxiety was a marginally significant in the overall model ($F(2,31) = 2.94, p = .07$). In line with our hypothesis, parent math anxiety predicted parents' talk about present sets of objects ($b = -11.97, p = .02$), as did SES and parent math anxiety interacted with SES, but math anxiety did not relate to talk about absent objects ($b = -1.67, p = .28$). However, the significant interaction between math anxiety and SES suggests that math anxiety might be more predictive of talk about number in the absence of objects for high, but not low, SES parents (see Table 6).

Table 6. Multivariate test of number talk with present or absent objects.

Variable	Multivariate Tests				Univariate Parameter Estimates		
	Λ	F	df ₁	df ₂	B	SE	95% CI:
SES	.723	5.94**	2	31			
Objects Present					30.35***+	10.03	9.91, 50.78
Objects Absent					9.37***+	3.12	3.02, 15.73
Math Anxiety	.841	2.94 ^a	2	31			
Objects Present					-11.97*+	4.86	-21.87, -2.07
Objects Absent					-1.67 ⁺	1.51	-4.75, 1.41
SES x Math Anxiety	.814	3.55*	2	31			
Objects Present					-10.68*+	5.08	-21.04, -.32
Objects Absent					-3.96*+	1.58	-7.19, -.742

^a $P < .10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$ + Follow-up comparisons: $F_{pMA}(1,64)=4.09, p=.047$; $F_{SES}(1,64)=3.99, p=.05$; $F_{SES*pMA}(1,64)=51.59, p=.212$.

2.4. Discussion

The current study presents some of the first findings demonstrating that parents' attitudes towards math are related to even the earliest type of math input that occurs at home – parents number talk. Specifically, we found that math anxiety is related to the quantity of parents' math input to their children. Though this relation was marginally significant, given the small sample size of this study, we take these results as a preliminary indication that math anxious parents avoid incorporating math talk into their routines at home with their young children. Furthermore, we found a significant interaction between parents' math anxiety and socioeconomic status, suggesting that math anxiety is having a greater impact on the number talk heard in higher-SES families' households.

We also found differences related to math anxiety with regards to the quality of parents' number talk. High math anxious parents were less likely to label the cardinal values of sets and to talk about present objects than were low math anxious parents, though there were no differences in the size of the numbers (e.g., 1-3, 4+) used in parents' number talk. Previous research supports labeling cardinal values of sets and talking about present objects as being “higher” quality number input, as these are the types of number talk which are most frequently found to relate to children's math knowledge (e.g., Casey et al., 2018; Elliott, et al., 2017; Gunderson & Levine, 2011; Ramani et al., 2015).

While we hypothesized that math anxiety would relate to use of large (4-10) but not small (1-3) numbers, we instead found that math anxiety did indeed predict use of small numbers, and only marginally predicted use of larger numbers. At first glance, this may seem surprising given the Gunderson and Levine (2011) and Elliot et al. (2017) findings that use of large numbers was more predictive of children's number knowledge. However, other work suggests that children's

prior knowledge is an important factor when considering the numbers parents should use with their children (Gibson, Gunderson and Levine, under review). In this study, parents were given small (1-3) and large (4-6) number books to take home and read to their children. Children who only knew the meanings of small number words (1 and 2) at pretest benefited from use of the small, but not large, number books, while children who understood the meanings of larger numbers (3 and 4), benefited from reading both books. Adjusting input based on a child's prior knowledge leads to the greatest benefits of input on learning, and it may be that the children in this sample still only understand the meanings of small number words, meaning use of large number words would not be qualitatively better. Furthermore, there is likely not enough variation in use of large number words between high- and low-math-anxious parents since we would expect use of these numbers to be low all around. Indeed, instances of large number talk in this sample only ranged from 0 to 30 instances (in contrast, instances of small number talk range from 1 to 114 instances).

Future work should also explore the co-occurrence of cardinal labeling and counting as it relates to parent math anxiety. For example, Mix et al. (2012) trained children on number words using one of four different training techniques: counting only, cardinal labeling only, cardinal labeling of sets immediately followed by counting, or alternating counting and cardinal labeling at each training session. They found that children only made gains in their understanding of number words in the condition that provided counting and cardinal labeling together, demonstrating that children benefit the most when these two types of math talk occur in conjunction with one another (Mix et al., 2012).

Additionally, future work would benefit from focusing on the types of objects parents are using in their number talk, as previous research has indicated that this might be an important

factor in children's ability to learn from the input they are receiving. For example, Peterson & McNeil (2013) found that perceptually rich objects hindered children's performance in a counting task, perhaps because children found the objects overly distracting and focused their attention on the objects themselves instead of the task. Small differences in the type of input and objects involved in various activities can lead to differences in children's learning and performance (Peterson & McNeil, 2013; Peterson et al., 2014).

This study focused on parents' math anxiety, but it is important to note that in nearly all instances where parent math anxiety related to number talk, the interaction between parent math anxiety and SES was also significantly related to parent number talk. This indicates that there may not be enough variation in the number talk of parents from low-SES backgrounds to detect differences based on math anxiety. Thus, boosting the quantity of number talk among low-SES families remains an important goal, but we should do so while taking into consideration how we can specifically support increases in high-quality interactions. Similarly, math anxiety impacted the types of number talk that occurred most frequently in our sample (cardinal talk, small number sets and talk about present objects). It may be that math anxiety relates to other types of number talk as well, but they occur too infrequently in our sample to be able to detect meaningful variation based on parents' anxiety levels.

Limitations

When considering these results, it is important to note that these findings are correlational in nature. Furthermore, the measure of parent math anxiety was obtained over 10 years after the observations of parent-child interactions were recorded. While there is some evidence to suggest that math anxiety is a relatively stable trait (Jennsen, Dunekacke, Eid, & Blomeke, 2015; but see Wigfield & Meece, 1988), it is difficult to draw any strong conclusions from this data given the

large time difference between collection of the measures. Additionally, while naturalistic observations provide a glimpse into what parents are doing at home, the nature of the interactions afforded minimal instances of number talk. Studying parent-child interactions at specific times of day (e.g., Susperreguy & Davis-Kean, 2016), or during activities that provide opportunities for rich number talk (e.g., Levya, Davis, & Skorb, 2018), will likely give a better sense of the types of math interactions that are occurring between parents and their children.

Conclusions

This study found that parents who are math anxious may miss out on opportunities to engage their children in rich number talk, and that parents' math anxiety starts to have an influence on parent-child math engagement even during the earliest years of a child's life. These results highlight the need for additional research examining how math anxiety impacts parent-child math engagement with regard to both the activities parents provide and the math talk children hear at home. Furthermore, these findings highlight the importance of supporting math engagement in homes with parents who are anxious about math. This can be done through the provision of materials that can be useful in promoting math learning at home, an idea we will explore in the next chapters of this dissertation.

3. CHAPTER THREE Study 2: The Relation Between Parent Math Anxiety and Parent Math Engagement at Home.

3.1. Background

As discussed in Chapter 1, variations in parents' engagement in math activities at home are associated with differences in the number knowledge that children possess at school entry (e.g., Gunderson & Levine, 2011; Skwarchuk, Sowinski & LeFevre, 2014), and these achievement gaps tend to persist throughout schooling (e.g., Duncan et al., 2007; Romano, Babchishin, Pagani, & Kohen, 2010). Thus far, there is evidence that factors such as parents' math ability and socio-economic background relate to both variation in parents' home numeracy practices and children's achievement in mathematics (e.g., Elliot et al., 2017; Skwarchuk et al., 2014). Further, research has found that parents' anxiety about math may have a negative impact on children's math achievement during the school years (Maloney et al., 2015; Soni & Kumari, 2015), yet little work has explored the impact of parents' math anxiety on parent involvement in children's education, especially during the critical period when children are transitioning from home to school. The results from Study 1 suggest that even the earliest type of math input, math talk in the home, is influenced by parents' feelings of anxiety around math. However, while these results indicate that there may be differences in the amount of number talk parents engage in with their children prior to the age of 3, they do not provide a complete picture of how parent math anxiety may influence broader aspects of parent involvement in math education.

One possibility is that math anxiety is directly linked to parents' engagement in math. As discussed in the introduction, math anxious individuals characteristically avoid math in all aspects of their lives, choosing college majors and career paths that allow them to avoid taking

math classes, and even avoid doing something as simple as calculating a tip at a restaurant (Ashcraft, 2002). Therefore, according to this account, math anxious parents might avoid interacting with their children in any meaningful math exchange, whether that be number talk, math-related games, or more formal math activities. Further, when math anxious parents do engage their children in math activities, it is likely to be of lower quality than the math input of non-math anxious parents. The results of Study 1, and Eason et al. (under review) support this proposal. Specifically, math anxious parents provide less math input to their young children, and when they do engage in math talk, the quality of the math interactions is of a lower caliber.

Another possibility, however, is that parent math anxiety has a negative impact on other parent characteristics, such as math self-efficacy, that influence parents' choices to be involved in their children's education. Hoover-Dempsey and colleagues (1995, 1997, 2001, 2005) found that a variety of factors influence parents' decisions to be involved in their children's education, including a sense of self-efficacy. According to self-efficacy theory (Bandura, 1977), negative experiences generally contribute to a lower self-efficacy, and indeed, math anxious individuals – who likely have negative associations with math – tend to have low math self-efficacy (Meece et al., 1990; Cooper & Robinson, 1991). In turn, lower math self-efficacy may lead to less frequent engagement in math activities with their children.

In the current study, we look at the influence of parent math anxiety on two different aspects of parent involvement during the preschool and kindergarten years. While past studies have found mixed results with regard to the importance of parents' school-based involvement, or engagement in activities such as homework help and providing opportunities for math learning at home, parents' attitudes towards educational achievement may be a particularly important part of parent involvement in math education. Therefore, we look at the influence of parent math anxiety

on parents' math self-efficacy, the math activities they engage in with their child at home, and the expectations and values that parents hold for their children in math.

3.1.2. The Present Study

Previously, we showed that parents' math anxiety is related to less math talk in the home and to differences in the quality of the math talk that children hear at home even before the age of 3. We further found that there was a significant interaction between parents' math anxiety and SES, such that math anxiety accounted for variation in number talk for high- but not low-SES parents. However, while early math talk is important for early number knowledge (e.g., Levine et al., 2010), as children get older, a critical component of parent involvement in education is the expectations and beliefs they hold about their children's potential for success. As reviewed in the Introduction and Chapter 2, lower-SES parents tend to engage their children in less complex mathematical activities, and parents' expectations and values for their children are associated with fewer math activities occurring in the home (e.g., DeFlorio & Beliakoff, 2015; Saxe et al., 1987). An open question, however, is how parents' math anxiety influences these aspects of parent involvement as children transition into more formal educational settings.

In the present study, we will use survey and observational data to examine how parent math anxiety relates to the frequency with which parents report engaging in a variety of math related activities with their pre-school and kindergarten aged children, as well as how parent math anxiety relates to their expectations and values for their children in math. We will also examine other factors known to relate to variation in parent math input, such as SES and parents' self-efficacy in math, to determine the unique impact of math anxiety on parents' math engagement.

3.2. Study 2A: Parents' Reports of Math Involvement

In our first test of the relation of parents' math anxiety to their involvement in their children's math education at home, we used a self-report measure asking parents about the extent to which they engaged their children in broadly defined math activities, as well as a questionnaire asking parents about their expectations for their children in math. Previous research has suggested that variation in the quantity of math activities that occur in the home and differences in parents' expectations for their children in math relate to children's math knowledge, and as such we examined how a variety of factors – parent math anxiety, parents' self-efficacy for helping their children in math, and SES – relate to variation in parent math involvement and their expectations about their children's math achievement. We also collected data on children's math achievement data for a subset of the participants in this study, and so we also look to see how parent math anxiety and parent involvement at home relates to children's math achievement even at school entry.

3.2.1. Methods

Participants

Parents of 537 Pre-K (n = 102) and Kindergarten (n = 435) children in the Chicagoland area participated in this study. 76% of parents who filled out the primary caregiver survey were the child's mother, while fathers made up 14% of survey respondents. The remaining 10% either did not respond to this question (6%) or had a different relationship with the child (1%). Approximately 42% of the sample was White, 13% was African-American, 30% was Hispanic/Latino, 4% was Asian, and the remaining 11% either identified as Biracial (5%) or Other (6%).

Procedure

Parents were recruited in two waves, as part two larger studies. The first wave of parents ($n = 317$) were initially recruited as part of a longitudinal study looking at the benefits of using a math-related iPad app. Research assistants attended back-to-school nights in the Fall of 2014 to inform parents about the study and to distribute consent forms. In order to receive the iPad with the math app preloaded onto it, parents were required to return a set of questionnaires to the research assistants.

The second wave of parents ($n = 220$), were recruited as part of a cross-sectional study on the way parents' beliefs and attitudes towards their children's academic abilities and potentials change as children progress through school. Surveys were distributed through students' classrooms during the 2016-7 school year, and parents were asked to mail the surveys back to the researchers. Parents received a \$10 gift card as a thank-you for filling out the surveys.

Surveys for both studies collected information about family income, race, and education level, and included questionnaires asking about parents' attitudes about math, their expectations and values of math for their children, and the math activities they engaged in with their children are home.

Measures

Parent Math and Reading Anxiety. As in Study 1, parent math anxiety was assessed using the short-Mathematics Anxiety Rating Scale (sMARS; Alexander & Martray, 1989; see Appendix A). This measure involved asking parents to rate how anxious different situations where they encountered math made them feel (e.g., calculating a tip at a restaurant, studying for a math test, etc.) on a scale of 1 (not anxious at all) to 5 (very anxious). All analyses were performed on the average of the 25 items on the scale.

Parents in the first wave of data collection also completed a 25-item reading anxiety questionnaire (see Appendix A). This questionnaire was adapted from the sMARS, and parents were asked to rate how anxious different situations where they encountered reading made them feel (e.g., being given a play to analyze, studying for an English test, etc.). Parents in the second wave of data collection completed a 5-item abbreviated version of this reading anxiety questionnaire. In order to control for reading anxiety in our analyses, in the current study we use only these 5-items as our measure of reading anxiety. The full and abbreviated forms of this questionnaire were highly correlated ($r = .97, p < .001$). Cronbach's alpha for the full version of the questionnaire was .97, and for the abbreviated version was .88.

Parent Self-Efficacy. Parents were asked about their confidence in their ability to help their children with their math and reading homework. Responses were rated on a scale of 1 to 5, with anchors ranging from “Not at all confident” to “Very confident” (see Appendix B). This question was meant to measure parents' math-self efficacy. Previous research suggests that parents' math-self efficacy when it comes to their children's education is tightly entwined with their perception of their ability to help with homework, and that parents' self-efficacy specifically around the idea of feeling competent enough to assist their children with their schoolwork related to their decision to become involved in their children's education (e.g., Eccles & Harold, 1993; Hoover-Dempsey & Sandler, 1995).

Parent Involvement Measures.

Parent-directed Math and Reading Activities. Parents were asked questions about the frequency with which they engaged in broad categories of math-related activities (e.g. math workbooks, educational math videos) with their children. They were asked similar questions regarding reading and literacy related activities. Responses were rated on a scale of 1 to 7, with

anchors ranging from “Never” to “More than Once a Day” (for complete surveys and scale, see Appendix B). The 6 questions that asked about parent-child math activities in the home were combined into a single composite measure that represented parents’ math activities. The Cronbach’s alpha for this scale is 0.75. Similarly, the 6 questions about reading activities in the home were combined into a single composite measure of reading activities at home, and this scale has a Cronbach’s alpha of 0.73.

Parent Expectations and Values for Their Children in Math and Reading. Parents were asked about their perceptions of their children’s abilities in math as well as their future expectations for their children in math (for complete survey see Appendix B). These questions were based on measures used in previous work in this area (Wigfield & Cambria, 2010). The questions were combined to create a single composite measure for the math questions and a second, parallel composite measure for the reading questions. The Cronbach’s alpha for this scale of all of these items combined was 0.69 for the math related questions, and .72 for the reading related questions.

Socio-economic Status. As in Study 1, we created a composite measure of SES based on family income and the educational attainment of the primary caregiver. These variables were collected categorically on the parent questionnaire and transformed into continuous scales. Mean education was 15.64 years, equivalent to being just short of bachelor’s degree ($SD = 2.14$ years, range=10 [less than high school] to 18 [master’s degree or higher]), and mean income was \$80,238 ($SD = \$42,159$, Range = less than \$15,000 to over \$100,000). Income and education were positively related ($r(486) = .597, p < .001$) and were combined into one SES variable using Principal Components Analysis. The analysis found one component, our composite SES score, which accounted for 80% of the original variance and weighted income and education positively

and equally. The composite SES score has a mean of 0 ($SD = 1$). Families with a high score on the SES composite have a high annual income and a primary caregiver with a high level of education.

Students' Math Achievement. As mentioned above, families from the first wave of data collection ($n = 317$) were part of a larger intervention study. As a measure of math performance for the children of parents in this group, we administered the WJ III Applied Problems subtest, a subtest on a nationally normed, comprehensive test battery used to assess achievement skills of individuals between the ages of 2 through 90 years (Woodcock, McGrew & Mather, 2001). The test consists of orally presented word problems that involve arithmetic calculations of increasing difficulty. For example, early problems involve single-digit arithmetic, while later problems involve money calculations and simple fractions. Testing continued until basal (six items correct in a row) and ceiling (six items incorrect in a row) were established. 12 children from this group were excluded from math achievement analyses due to experimenter error leading to failure to achieve either a basal or ceiling on this subtest. Students' raw scores on this assessment are converted into a Rasch-scale with equal intervals, called a W score (a W score of 500 is the approximate average performance of a 10-year-old). The mean W score was 429.89 ($SD = 21.87$) and ranged from 332 to 481.

3.2.2. Results

Descriptive statistics for parents' math and reading anxiety, reported parent-child math and reading activities, parents expectations and values of math and reading, and parents' confidence in their ability to help their children with homework can be found in Table 7. Paired-sample t-tests confirmed that, as we would expect, parents' math anxiety was significantly higher than parents' reading anxiety, and parents report having lower confidence in their ability to help

their children with math versus reading homework (self-efficacy), engaging their children more frequently in reading activities than in math activities, and holding lower expectations and values for their children in math than in reading (see Table 7).

Table 7. Means and SD of parent measures.

	Mean	SD	Min	Max	t-test
Parent Math Anxiety (pMA)	2.17	.90	1	5	$t(532) = 6.99,$
Parent Reading Anxiety (pRA)	1.90	.94	1	5	$p < .001$
Math Self-Efficacy	4.59	.66	1	5	$t(526) = -4.22,$
Reading Self-Efficacy	4.69	.60	1	5	$p < .001$
Math Activity Average	4.14	1.02	1	7	$t(535) = -12.88$
Reading Activity Average	4.53	1.04	1	7	$p < .001$
Math Expectations-Values (EV)	4.12	.60	1.5	5	$t(530) = -3.09,$
Reading EV	4.18	.60	1.75	5	$p = .002$

Relation of parent math anxiety and parent engagement in math activities with their children.

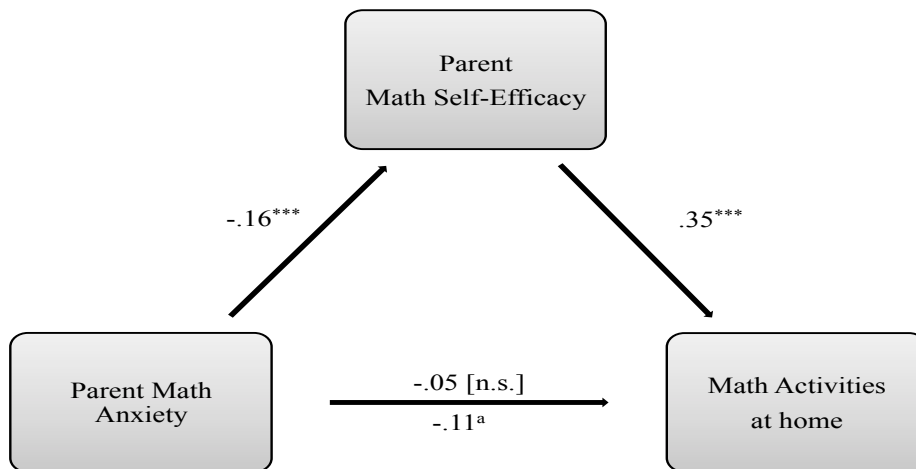
Correlations among all variables are in Table 8. Consistent with past research, our SES variable was related to the frequency with which parents engaged their children in both math and reading activities, in addition to being correlated with parents' math and reading anxiety, as well as their confidence in their ability to help with their children's homework. Interestingly, while SES was correlated with parents' expectations and values for their children in reading, it was not correlated with their expectations and values for their children's math achievement.

Table 8. Zero-order correlations for all measures

	1	2	3	4	5	6	7	8	9
1. SES	--								
2. pMA	-.264**	--							
3. pRA	-.228**	.549**	--						
4. Math Self-Efficacy	.175**	-.259**	-.165**	--					
5. Reading Self-Efficacy	.155**	-.136**	-.182**	.655**	--				
6. Math Activities	-.263**	-.041	-.020	.179**	.087*	--			
7. Reading Activities	-.221**	.023	-.034	.118**	.139**	.769**	--		
8. Math EV	.076	-.193**	-.138**	.258**	.178**	.258**	.193**	--	
9. Reading EV	.117*	-.145**	-.185**	.240**	.275**	.194**	.242**	.658**	--
10. Math Achievement (Wave 1 sample only)	.256**	-.108 ^a	.024	.116*	.049	.057	-.026	.435**	.341**

^a $P < .10$; * $P < 0.05$; ** $P < 0.01$

We next tested our hypothesis that parents' math anxiety would predict the frequency with which they reported engaging their children in math activities at home (while controlling for SES and reading anxiety) and in their expectations and values for their children in math. A regression analysis using the PROCESS macro for SPSS (Hayes, 2018) established that parents' math anxiety had a significant negative effect on parents' math self-efficacy ($b = -.16$, $SE = .04$, 95% CI [-.24, -.09]) and parents' math self-efficacy had a significant effect on math activities in the home ($b = .35$, $SE = .07$, 95% CI [.22, .49]). While parent math anxiety did not have a significant direct effect on the frequency of math activities occurring in the home ($b = -.11$, $SE = .06$, 95% CI [-.26, .01]), the indirect effect of math anxiety on the math activities parents' engage in with their children at home, tested using a bootstrap estimation approach with 5000 samples, was significant ($b = -.06$, $SE = .02$, 95% CI [-.10, -.02]), meaning parents' math anxiety is indirectly influencing the math activities that happen in homes via its negative effect on parents' math self-efficacy (see Figure 2).

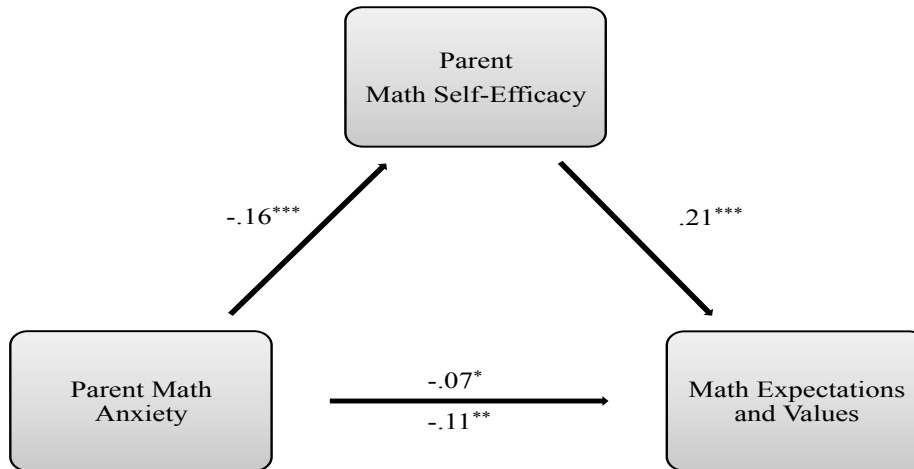


^a $P < .10$; *** $P < 0.001$

Figure 2. Relation of Parent Math Anxiety to Frequency of Math Activities at Home. Parent math anxiety has a significant indirect effect on the frequency of math activities parents and children engage in at home, via parents' math self-efficacy.

We then re-ran the model replacing math activities in the home with parents' expectations and values for their children in math (see Figure 3). Parents' math anxiety had a significant direct negative effect on parents' expectations and values for their children in math ($b = -.11$, $SE = .04$, 95% CI $[-.18, -.03]$; see Table 9). As expected, parent math anxiety also had a significant, negative effect on parents' math self-efficacy ($b = -.16$, $SE = .04$, 95% CI $[-.23, -.08]$; see Table 10). When parent math anxiety and math self-efficacy were entered as predictors of expectations and values in math simultaneously, the effect of parents' math anxiety on parents' math expectations and values was reduced but remained significant ($b = -.07$, $SE = .04$, 95% CI $[-.14, -.0006]$), and math self-efficacy was also a significant predictor of expectations and values ($b = .21$, $SE = .04$, 95% CI $[.13, .29]$; see Table 9). The indirect effect of math anxiety on parents' expectations and values of math was tested using a bootstrap estimation approach with 5000 samples. The results indicated that the indirect coefficient was significant ($b = -.03$,

SE = .01, 95% CI [-.06, -.01]), indicating that parents' math self-efficacy is a partial mediator of the relation between parents' math anxiety and their expectations for their children's ability and success in math.



$P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Figure 3. Relation of Parent Math Anxiety to Parents' Expectations and Values of Math for their children. Parent math anxiety has a significant indirect effect on parents' expectations and values for their children in math, which is partially mediated by parents' math self-efficacy.

Table 9. Relation of parent math anxiety, parent self-efficacy, and parent math involvement

	Frequency of Math Activities		Math Expectations and Values	
	Unstandardized Parameter Estimates			
	Model 1	Model 3	Model 1	Model 3
Constant	4.39*** (0.13)	2.63** (0.37)	4.44*** (.08)	3.38*** (0.23)
Parent Math Anxiety	-.11 ^a (0.06)	-.05 (0.06)	-.11** (.04)	-.07* (0.04)
Parent Math Self-Efficacy	–	.35*** (0.07)	–	0.21*** (.03)
SES	-.31*** (0.05)	-.33*** (0.05)	.01 (.03)	-.01 (.03)
Parent Reading Anxiety	-.02 (0.06)	-.01 (0.06)	.06 (.04)	-.05 (.03)

Numbers in parentheses are SEs

^a $P < .10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 10. Relation of parent math anxiety to parent math self-efficacy

	Model 2
	Unstandardized Parameter Estimates
Constant	4.95*** (.08)
Parent Math Anxiety	-.16*** (.04)
SES	.07* (.03)
Parent Reading Anxiety	-.01 (.04)

Numbers in parentheses are SEs

^a $P < .10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Relation of parent reading anxiety and parent engagement in reading activities with their children.

We also wanted to examine whether the relation of parents' math anxiety to their involvement in math at home was specific to the domain of math or if it extended to other areas as well. We therefore ran a parallel mediation model to the ones tested above to examine the relations between parent reading anxiety, parents' expectations for their children in reading and the frequency with which parents report engaging their children in reading related activities (zero-order correlations can be found in Table 8). We found that parent reading anxiety (controlling for SES and math anxiety) had a direct effect on parents' expectations for their children in reading ($b = -.10$, $SE = .03$, 95% CI [-.17, -.04]; see Table 11) and on parents' reading self-efficacy ($b = -.09$, $SE = .04$, 95% CI [-.16, -.02]; see Table 12), but not on the frequency with which they engaged in various reading related activities at home ($b = -.09$, $SE = .06$, 95% CI [-.21, .03]; see Table 11). However, the indirect effects of parent reading anxiety on both types of parent involvement were significant (reading expectations and values: $b = -.02$, $SE = .01$, 95% CI [-.04, -.004]; reading activities: $b = -.02$, $SE = .01$, 95% CI [-.06, -.002]).

Table 11. Relation of parent reading anxiety, parent self-efficacy, and parent reading involvement

	Frequency of Reading Activities		Reading Expectations and Values	
	Unstandardized Parameter Estimates			
	Model 1	Model 3	Model 1	Model 3
Constant	4.67*** (.13)	3.40*** (.39)	4.43*** (.08)	3.27*** (.23)
Parent Reading Anxiety	-0.09 (.06)	-.07 (.06)	-.11** (.03)	-.08* (.03)
Parent Reading Self-Efficacy	–	.26*** (.08)	–	.24*** (.04)
SES	0.25*** (.05)	-.27*** (.05)	.04 (.03)	.02 (.03)
Parent Math Anxiety	-.01 (.06)	.01 (.06)	-.03 (.04)	-.03 (.04)

Numbers in parentheses are SEs

^a $P < .10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Table 12. Relation of parent reading anxiety to parent reading self-efficacy
Model 2

	Unstandardized Parameter Estimates
	Constant
Parent Reading Anxiety	-0.09** (.04)
SES	0.07* (.03)
Parent Math Anxiety	-.01 (.04)

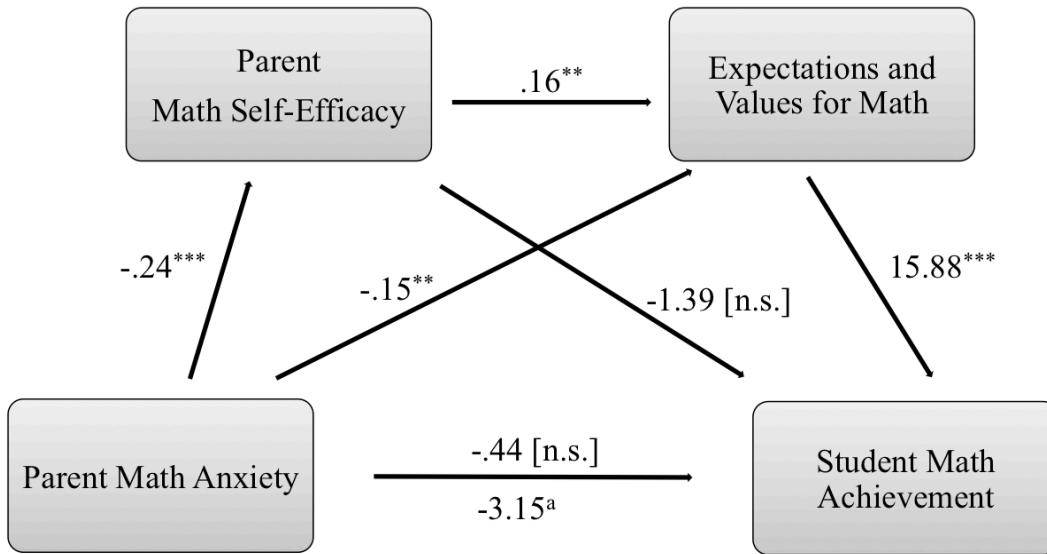
Numbers in parentheses are SEs

^a $P < .10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Relation of Parent Math Anxiety to Children’s Math Achievement.

We next wanted to see if parent math anxiety was negatively related to children’s math knowledge at school entry. As part of a longitudinal study, children of parents from the first wave of data collection completed a battery of assessments, including a measure of math achievement at the beginning of the school year when parent surveys were distributed. To look at the direct and indirect effects of parent math anxiety on student math achievement, we first ran a mediation model that included parents’ math self-efficacy, expectations and values for their children in math, and frequency of engaging in various math activities at home. However, our measure of math activities at home did not predict student achievement, nor were any of the pathways involving math activities significant. We therefore dropped this variable from the

model and re-ran the model with just two mediators (math self-efficacy and math expectations and values; see Figure 4).



^a $P < .10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

Figure 4. Relation of Parent Math Anxiety to Student Math Knowledge at beginning of preschool and kindergarten. Parent math self-efficacy and expectations and values for their children in math mediate the relation between parent math anxiety and student math achievement.

While parent math anxiety only marginally related to children’s performance on our measure of math knowledge at school entry (see Table 13), we did find a significant indirect effect of parent math anxiety on student math achievement ($b = -2.71$, $SE = 1.11$, $95\% \text{ CI } [-5.18, -.78]$). The majority of this indirect effect was accounted for by the pathway through parents’ expectations and values for their children in math ($b = -2.41$, $SE = 1.00$, $95\% \text{ CI } [-4.58, -.69]$), though there was also a significant indirect effect via the pathway through both mediators ($b = -.64$, $SE = .31$, $95\% \text{ CI } [-1.38, -.13]$).

Table 13. Effect of parent math anxiety on student math knowledge at the start of formal schooling, mediated by parents' math self-efficacy and expectations and values for their children in math.

Outcome:	Student Math	Parent Math	Parent Expectations	
	Achievement	Self-Efficacy	and Values in Math	
	Unstandardized Parameter Estimates			
	Model 1	Model 4	Model 2	Model 3
Constant	434.05*** (4.27)	371.00*** (13.76)	5.01*** (.12)	3.56*** (.32)
Parent Math Anxiety	-3.14 ^a (1.94)	-.44 (1.88)	-.24*** (.05)	-.15** (.05)
Parent Math Self-Efficacy		-1.39 (2.13)		.16** (.06)
Parent Expectations and Values for Math		15.88*** (2.21)		
SES	6.15** (1.61)	5.90*** (1.48)	.06 (.04)	.01 (.04)
Parent Reading Anxiety	.50 (2.02)	.73 (1.85)	.04 (.48)	-.02 (.05)

Numbers in parentheses are SEs

^a $P < .10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

3.2.3. Discussion

The results of Study 2A show that parents' math anxiety influences the frequency with which parents report engaging with their children in broadly defined math activities at home, and their expectations and values for their children in math, and that this relation is mediated by parents' math self-efficacy. Moreover, we found that the pathway by which parents' anxiety relates to their engagement in activities in an academic domain is not limited to mathematics – parents' reading anxiety has an indirect effect on engagement with reading activities at home and on parents' expectations and values for their children in reading, as mediated by parents' math self-efficacy. This suggests that in general, parents' feelings of anxiety about a particular academic domain may be both directly and indirectly impacting their choices about how and when to get involved in their children's education.

While the results obtained here suggest that math anxious parents are engaging their children in fewer math activities, only parents' expectations and values for their children in math directly related to children's math knowledge at school entry. This is in line with previous research findings showing that specifically parent involvement that falls under the umbrella of parents' expectations and values predicts student achievement in school (e.g., Grolnick & Slowiaczek, 1994; Hill & Tyson, 2004). Why might this be the case? One possibility is that the activities we asked parents about were too broadly defined (e.g. "math related TV, videos and board games" can mean different things to different parents), and so we may not have accurately captured the diversity that exists in the types, frequency and quality of math activities that happen at home. Additionally, the measure of math achievement used here – the Woodcock-Johnson Applied Problems subtest – measures children's ability to solve word problems, which requires the child to be able to analyze, recognize the procedure to follow, and calculate the answer, and it is likely that the math activities that foster these skills were not captured by our measure of parent-directed math activities. While there is some research suggesting that a general home math factor relates to children's math skills (Purpera, Napoli, Wehrspann, & Gold, 2017), other research points towards direct (counting, simple sums, etc.) and indirect (playing card games, playing "store", etc.) math activities as being important for the development of children's math abilities (e.g., Blevins-Knabe & Musun-Miller, 1996; LeFevre, Clarke & Stringer, 2002).

These data, combined with the results from Study 1, suggest that math anxious parents are providing both less frequent and lower quality math input. However, as previously discussed, Study 1 did not look specifically at math input during activities that were designed to elicit math talk but rather was based on naturalistic observations of families at random times of the day.

Therefore, in Study 2B, we seek to examine how parent input during a math-related activity varies based on parents' math anxiety, and whether providing parents with materials that subtly encourage talk about numbers can boost the math talk that children of math anxious parents hear during math-related activities.

3.3. Study 2B: Parent Math Anxiety and Parent Number Talk During Toy Play

In Study 2A, we asked whether parent math anxiety relates to different types of parent involvement in education at home. Specifically, we looked at parents' frequency of engagement in math-related activities with their children, and their expectations and values for their children in math. The results of this study showed that parent math anxiety relates to both types of parent involvement, but an open question is how parent math anxiety influences the quality of these math activities when they do occur at home. To probe the impact of parent math anxiety on the math activities they engage in with their children, the current study combines both self-report and observational measures to look at both the reported frequency of math activities at home and parent math talk during one such activity.

In addition to this main question, this study also explores a secondary question related to the relation between parents' self-report and observational measures of parent math engagement. Prior work on home numeracy practices has highlighted that these different methodologies may each reflect separate qualities of the home numeracy environment (Mutaf, Sasanguie, De Smedt & Reynvoet, 2017). Additionally, each of these methodologies also has weaknesses that the other can help account for. When using self-report measures, parents may not accurately recall the frequency with which they engage in various activities. Observational studies, on the other hand, are constrained to a limited amount of time, and when conducted in the lab may lead to parents being cued in to talk about math. Therefore, Study 2B uses both of these methodologies to allow

us to observe whether there are measurable differences in the ways in which parents who are higher in math anxiety engage their children in toy play (both with and without cues to talk about number), how these differences relate to parents' expectations and values for their children in math, and to compare parents' self-report of the activities they engage in with their child to their observed number talk.

3.3.1. Methods

Participants

Forty-four mother-child dyads (26 females) participated in the study. The mean age of the children was 5.46 years ($SD = .65$, Range = 3.9 – 6.9 years). Participants were recruited from respondents to the surveys distributed as part of Wave 2 of data collection in Study 2A, as well as from a database of registered families who were willing to participate in research studies at the University of Chicago. The average income of participants in this study was \$95,833 ($SD = \$63,767$, Range = less than \$15,000 to over \$190,000). The average parent education level was 16.2 years of school (equivalent to a Bachelor's degree; $SD = 2.12$, Range = 12 [high school graduate] to 18 [graduate degree]). An additional 7 dyads were tested in this study but are excluded from analyses due to experimenter error ($n = 3$), the parent attending the in-lab session was the child's father and not the mother ($n = 3$), and the parent speaking a foreign language for over 50% of the interaction ($n = 1$).

Procedure

Parents who were recruited via the database were asked to fill out the parent questionnaire prior to their visit to the lab with their child. In the lab, parents and children were observed playing together with a sorting pie toy (see Figure 5) for 6 minutes. The parent-child dyad was told that they would be left on their own to play together in the room, with the only

stipulation being that they incorporate the provided toy into their play. The researcher then left the room while the interaction was recorded on a video camera. Importantly, no explicit instructions were given as to how to play with the toy; parents and children were free to use the toy in the way that most appealed to them. After 6 minutes, the research assistant returned and brought in an additional component to the toy, round paper cards that provided suggestions for how to sort the objects (i.e., by shape, color, number, etc.) and which served as a cue to encourage parents to talk about number. The experimenter apologized for “forgetting” these pieces at the outset of the study, and then once again left the dyad alone in the room to continue playing with the toy for another 6 minutes.



Figure 5. Sorting pie toy that forms the basis of the parent-child in lab interaction. This toy invites parents and children to engage in rich pretend play as well as providing opportunities to discuss numbers, shapes and colors. Small discs that can be inserted at the bottom of the pie provide suggestions to parents for different methods of sorting the fruit (e.g. shape, number and color) and were only provided to the dyads during the second half of the observation.

Materials. The sorting pie toy consisted of small (plastic) pieces of fruit in varying colors. Prior to the start of the study, the experimenters removed some of the pieces so that there were different numbers of each type of fruit and color that could serve as a subtle cue to talk about number. The fruit pieces were placed in a large pie dish with five subsections, which allow for easily sorting the pieces into different categories (see Figure 5). Importantly, this toy lends itself to rich and engaged pretend play, where math talk would be easy to incorporate but is not a necessity.

Coding and Reliability. All speech was transcribed by an outside transcription company at the utterance level, defined as any sequence of words preceded and followed by a pause, change in conversational turn, or change in intonational pattern. Dictionary words, onomatopoeic sounds (e.g. meow) and evaluative sounds (e.g. uh-oh), were counted as words. All transcriptions were reviewed by an experimenter to check for accuracy. Since the transcription company only had access to the audio of the interaction, and the experimenter was able to garner more about the context from the video of the interaction, all disagreements in transcription went with the experimenter.

Measures

Parent Number Talk. Audio recordings of the parent-child interactions were transcribed verbatim at the level of the utterance by a professional transcription service. We then used the video recordings to verify the parent talk and to ensure that the transcripts adhered to the Codes for the Human Analysis of Transcripts (CHAT) conventions of the Child Language Data Exchange System (CHILDES, MacWhinney, 2000). Transcripts were then searched via computer for the total frequency of number words ‘one’ through ‘one-hundred’ using the CLAN FREQ command. As in Study 1, all instances of the word ‘one’ were manually coded as either numerical (e.g. cardinal values) or non-numerical (e.g. deictics). A second research assistant coded 20% of the utterances that included the word ‘one’ and achieved 93% agreement. Disagreements were resolved by following the coding of the more experienced coder. Non-numerical uses of ‘one’ were excluded from the parent and child measures of number tokens and types. Number talk was coded separately for the two halves of the session (before and after the cues to sort the objects by number, shape or color was provided).

Parent Questionnaires. Prior to coming in to the lab, parents completed a survey that included questions about demographic information, their attitudes and beliefs about math and reading, and the frequency with which they engaged their children in a variety of different math and reading activities at home.

Math and Reading Anxiety. Parent math anxiety was again assessed using the short-Mathematics Anxiety Rating Scale (sMARS; Alexander & Martray, 1989; see Appendix A), a 25-item scale. All parents also completed the 5-item abbreviated version of the reading anxiety questionnaire used in Experiment 1 (see Appendix A). Average parent math anxiety was 2.18 ($SD = .76$, Range = 1.08 – 4.04), and average reading anxiety was 1.53 ($SD = 0.60$, Range = 1 – 3); the difference between math and reading anxiety was statistically significant, $t(43) = 4.71$, $p < .001$.

Expectations and Values. Parents' expectations and values of math and reading for their children were measured using the same questions as in Study 2A (Appendix B). The scale was internally consistent for this sample ($\alpha_{\text{math}} = .71$; $\alpha_{\text{reading}} = .70$). For the questions pertaining to math, scores ranged from 2 to 5 with a mean of 4.05 ($SD = .67$), while for reading scores ranged from 3 to 5 with a mean 4.20 ($SD = .60$); this difference was marginally significant, $t(43) = -1.91$, $p = .062$.

Frequency of Parent-directed Math and Reading Activities. As in Study 2A, parents were asked questions about the frequency with which they engaged in broad categories of math- and reading-related activities (e.g. math or reading workbooks, educational math or reading videos) with their children (Appendix B). This scale was internally consistent for this sample ($\alpha_{\text{math}} = .72$; $\alpha_{\text{reading}} = .62$). Average frequency of engaging in math activities was 4.07 (equivalent to once

a week on the scale; $SD = 1.08$, Range = 1.33 – 6.17) and reading activities was 4.36 ($SD = 0.99$, Range = 2.17 – 6.17); this difference was statistically significant, $t(43) = -2.64, p = .012$.

Socio-economic Status. As in Studies 1 and 2A, we created a composite measure of SES based on family income and the educational attainment of the primary caregiver. These variables were collected categorically on the parent questionnaire and transformed into continuous scales. Mean education was 16.2 years, equivalent to a bachelor's degree ($SD = 2.14$ years, range=12 [high school degree] to 18 [master's degree or higher]), and mean income was \$93,523 ($SD = \$64,472$, Range = less than \$15,000 to over \$190,000). Income and education were positively related ($r(44) = .502, p < .001$) and were combined into one SES variable using Principal Components Analysis. The analysis found one component, our composite SES score, which accounted for 75% of the original variance and weighted income and education positively and equally. The composite SES score has a mean of 0 ($SD = 1$). Families with a high score on the SES composite have a high annual income and a primary caregiver with a high level of education.

3.3.2. Results

Descriptive statistics on the amount of parent cumulative number talk during both the first and second half of the in-lab observation can be found in Table 14. Parents varied widely in their use of number words, especially during the first half of the interaction, and most number talk throughout the entire session involved the numbers one through ten. Interestingly, average number tokens did not significantly differ between the first six minutes and second six minutes of the interaction.

Table 14. Mean and range of parent number talk

	Mean (<i>SD</i>)	Min	Max	t-test
Parent Number Talk				
First half	14.43 (<i>19.56</i>)	0	101	t(43) = .277, <i>p</i> = .783
Second half	13.70 (<i>12.01</i>)	0	43	

Relation of parent math anxiety and parent math involvement to parent number talk.

Correlations among all variables of interest are in Table 15. In contrast to previous findings, our SES variable was not related to parents’ number word tokens during either portion of the parent-child interaction. Interestingly, however, SES was related to parents’ math anxiety ($r = -.427, p < .001$) but not to parents’ reading anxiety ($r = -.034, p = .824$), and to parents’ expectations and values of reading for their children ($r = .352, p = .019$), but not their expectations and values of math for their children ($r = .189, p = .219$). Additionally, we found no relation of our measures of parent directed math activities to parents’ number talk during either half of the parent-child interaction (see Table 15).

Table 15. Zero-order correlations for variables of interest

	1	2	3	4	5	6	7	8
1. SES	--							
2. pMA	-.472***	--						
3. pRA	-.034	.095	--					
4. Math EV	.189	-.214	-.184	--				
5. Reading EV	.352*	-.182	-.375*	.655**	--			
6. Math Activities	-.151	.207	.02	.212	.017	--		
7. Reading Activities	-.204	.309*	-.074	-.026	-.127	.744**	--	
8. Parent Number Word Tokens (First Half)	.159	-.245	.064	-.127	-.133	-.048	-.016	--
9. Parent Number Word Tokens (Second Half)	.224	-.269	.389**	-.025	-.07	-.056	-.062	.478**

^a $P < .10$; * $P < 0.05$; ** $P < 0.01$

We next tested our hypothesis that parents’ math anxiety related to the number talk they engaged in with their children during the in-lab observation. Since our outcome variable of interest was count data (count of number word tokens used during each of the two halves of the

interaction), contained no negative values and had a skewed distribution, we used a negative binomial regression with a log link to explore the relation between parent math anxiety and number talk (controlling for reading anxiety and child’s age¹). We found that parent math anxiety was a significant predictor of parents’ number talk during the first portion of the interaction, when parents and children were told to play with the toy however they wished ($b = -.560, p = .008$; see Table 16), but was only a marginally significant predictor during the second half of the interaction, when parents and children were provided with a subtle cue (a disk with numbers) to talk about numbers during their toy play ($b = -.409, p = .06$; see Figure 6).

Table 16. Effect of parent math anxiety on parent number talk during parent-child interaction.

	Parent Number Tokens During First Half of Toy Play	Parent Number Tokens During Second Half of Toy Play
	Unstandardized Parameter Estimates	
Intercept	4.598*** (1.41)	3.277* (1.38)
Parent Math Anxiety	-.560** (.21)	-.409 ^a (.22)
Parent Reading Anxiety	.451 (.28)	.506* (.25)
Child’s Age	-.271 (.24)	-.114 (.24)

Numbers in parentheses are SEs

^a $P < .10$; * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$

¹ We first ran a model that included SES and the interaction between parent math anxiety and SES. However, we found no effect of the interaction of SES with parent math anxiety and no main effect of SES, so we dropped these two terms to create a more parsimonious model.

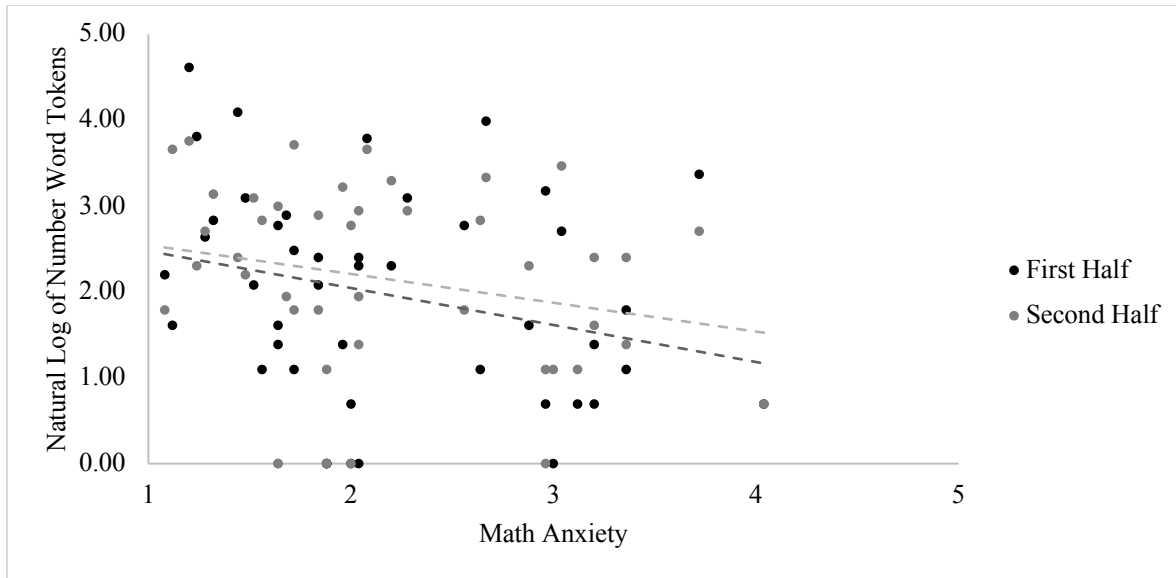


Figure 6. Relation of Parent Math Anxiety to Parent Number Talk. During the first half of the parent-child interaction parent math anxiety was significantly related to parent number talk, but this relation became only marginally significant during the second portion of the interaction.

Quality of Parent Number Talk

While parent math anxiety related to variation in the quantity of parent number talk, it also likely relates to differences in the quality of the number interactions parents were having with their children. Indeed, a closer look at the interactions between parents and children that included number suggests that lower math anxious parents were more comfortable talking about more advanced math concepts than their higher math anxious counterparts. For instance, in the following example, a low-math anxious parent talks about the characteristics of a number (i.e., even versus odd; more than or less than, etc.), rather than just counting or labeling the set and moving on:

Example 1: Low math anxious² mother A

MOTHER: You have three and three, right?

² Based on median split of parent math anxiety. Low math anxious parent fell over 1 standard deviation below the mean of parent math anxiety, and high math anxious parent was over 1 standard deviation above the mean.

CHILD: Nope.
CHILD: Two.
MOTHER: Two and three, so it's another odd number.
MOTHER: Do you xxx.
MOTHER: There you go see the pattern?
.....
MOTHER: So which one had the most?
MOTHER: Do you remember?
CHILD: I think definitely the grapes or the apples.
MOTHER: Two, four, six, eight, ten.
MOTHER: So you have ten grapes

In contrast, a high math anxious mother talking with her child about numbers does not use this opportunity to probe her child about more advanced mathematical concepts:

Example 2: High math anxious mother A

MOTHER: Okay and how many purple grapes?
CHILD: Um, one, two, three, four, five, six.
MOTHER: So three plus six is what?
MOTHER: Um, ten.
MOTHER: One, two, three, four, five, six, seven, eight, nine, ten.
MOTHER: Good job.
MOTHER: So, altogether, we have ten grapes.
MOTHER: So how many oranges do we have?
CHILD: We have +/.
MOTHER: How many oranges?
CHILD: Four and one banana.
MOTHER: How many apples?
MOTHER: Count.
CHILD: One, two, three, four, five.
MOTHER: Okay.
MOTHER: How many yellow bananas?

Similarly, low math anxious parents might be more comfortable asking their children questions that prompt their child to talk more about number and other aspects of math, or providing their children with better feedback when they respond incorrectly, as in the following example:

Example 3: Low math anxious mother B

MOTHER: What shape is that?

CHILD: Triangle.
MOTHER: Mmhm.
MOTHER: So how many triangles that makes up the piece of the pie that you have?
CHILD: Three.
MOTHER: Mmmm, keep counting.
MOTHER: Count all the pieces of the pie.
CHILD: One, two, three, four, five.
MOTHER: Ah.
MOTHER: So how many pieces of pie do we have?
CHILD: Five.

On the other hand, high math anxious parents might give their children less opportunity to respond to their prompts, or be less persistent in talking about number and counting if their child seems disinterested, as in the following two examples:

Example 4: High math anxious mother B

MOTHER: You know what, I want to try something.
MOTHER: I mean, thank you.
MOTHER: Now you try one of these number ones, I've got an idea.
MOTHER: One, two, three, four and (...) five.
MOTHER: Okay, six, seven, eight &=laughs.
MOTHER: Just like sorting by color (...) tada.

Example 5: High math anxious mother C

MOTHER: We were going to see how many.
MOTHER: Let's get all the yellow ones out first and then we'll count how many different fruits there are.
CHILD: I don't want to do that.
MOTHER: Okay.
MOTHER: We don't have to.

These excerpts suggest that even when high math anxious parents are talking about number, they are doing so in ways that are less productive than low math anxious parents and may need better supports to have effective and meaningful math interactions with their children.

3.3.3. Discussion

The results of this study show that parent math anxiety relates to parents' number talk with their children during a toy-based activity. Importantly, parent math anxiety was significantly related to their number talk at the beginning of the interaction when we provided no direct cues to talk about numerosity with the toy but was only marginally related to number talk once parents were provided with a prompt to talk about number. This suggests that even when math anxious parents are engaging their children in activities that could be used to encourage math learning, they are missing the opportunity to provide their children with additional math input unless explicitly told to do so.

It is also important to note that while the present study found a significant negative relation between parent math anxiety and parent number talk during the first half of the interaction, and only a marginally significant relation during the second half, these two coefficients were not themselves significantly different from one another³. There are several reasons why we may not see a larger shift in number talk from one half of the interaction to the next. First, many parents and children were deeply involved in pretend play with the toy when the experimenter re-entered the room to drop off the paper sorting cards. Once the experimenter left, the dyads often picked up their game where it had been interrupted, and only after a few minutes turned to the additional resources the experimenter had delivered. As a result, six minutes may not have been a sufficient amount of time to really capture how parents and children utilized the cue to talk about numbers. Second, the cue to talk about number may have

³ Despite the lack of a significant difference, the direction of number talk goes in the expected direction for high- and low-math anxious parents. Math talk slightly decreases among low math anxious parents, who have already talked about number during the first half of the interaction. In contrast, math talk increases among high math anxious parents who were likely avoiding math in the first half of the interaction.

been too subtle to see any significant shift in number talk. Other studies that have utilized explicit instructions to parents to support their children's number learning in informal contexts have found significant shifts in parents' number talk (Vandermaas-Peeler, Ferretti, & Loving, 2012; Vandermaas-Peeler, Boomgarden, Finn, & Pittard, 2012), suggesting that it is possible to enhance parent math supports during toy play.

An open question with regards to the relation between parent math anxiety and number talk is about the quality of the number talk that is taking place during these activities. While this study found differences in the overall amount of number talk and took a superficial look at differences in how parents talk about number, we did not fully explore the specific types of number talk (i.e. counting, cardinal labeling, simple sums, etc.) that are taking place during these interactions. Previous work has found that more advanced number talk (i.e. cardinality, ordinal relations, and arithmetic), is more predictive of children's math knowledge than more foundational number talk (i.e. counting, numerical identification) (Casey et al., 2018; Ramani et al., 2015). Our preliminary look at the types of number talk happening during the interactions suggest that low math anxious parents may be providing more advanced number talk than high math anxious parents, and so this is an important next step in exploring these interactions.

In addition to exploring the specifics of parents' number talk, we can also think about looking at how parent math anxiety relates to broader categories of math talk. Other research has shown that it is specifically parents' prompts to talk about number (e.g. asking "how many?"), and not their number statements, that are the best predictors of children's own number talk (Eason et al., under review). Furthermore, the toy used provided an opportunity to talk about different shapes and patterns, both of which are important types of math talk since spatial and patterning abilities have been identified as critical skills for math learning (e.g., Nguyen, Watts,

Duncan, Clements, Sarama, Wolfe, & Spitler, 2016), but which are not captured by our measure of parents' number talk.

Finally, another ripe avenue for exploration is the degree to which the interactions were parent or child driven. Many parents chose to sit back and let their child decide how they would play with the pie, whether it be by simply making a fruit pie, sorting shapes and colors, or counting out objects and making patterns. It would be interesting to see if parents' math anxiety related to whether parents attempted to steer the play towards math-related content, and their persistence in bringing the conversation around to math-related concepts.

3.4. General Discussion

The present study found that parents' math anxiety relates to parents' involvement in their children's math learning during the critical time period when children are transitioning from home to school. Specifically, we found that parents' math anxiety related to parents' expectations and values of math for their children, and to the frequency with which they reported engaging their children in math-related activities at home, and that these relations were mediated by parents' math self-efficacy. Furthermore, as in previous work (Study 1; Eason et al., under review), we found that parents' math anxiety related to the number talk they engaged in with their children during a toy-based activity.

This study also demonstrated that parents' math anxiety has an indirect effect on their children's math knowledge as they enter school, highlighting the importance of supporting math anxious parents in a way that enables them to have positive math-related interactions with their children. Previous work has shown that it is possible to enhance the conversations that parents have with their children and that these interventions result in improved child performance on measures of math knowledge. For example, sending children home with number books for

parents to read with their young children, led to children making greater gains in their number word learning than children in a control group (Gibson, Gunderson, & Levine, under review). Additionally, Study 2B suggests that providing parents with a subtle cue to talk about number during toy play helped math anxious parents incorporate number talk into their pretend play. However, it remains unclear whether interventions that increase the math-related interactions between parents and children would be beneficial to children's math learning, since previous research has also found that when math-anxious parents help their children with homework more frequently, their children learn less math over the course of a school year than their peers (Maloney et al., 2015).

Therefore, an open question is whether the relationship between parent math anxiety and parent-child math interactions, and the negative influence parent math anxiety has on children's achievement in elementary school, can be ameliorated via an intervention. The results of this study suggest that parent math anxiety has a negative effect on young children's math achievement because math anxiety leads to lower math self-efficacy and to parents holding lower expectations and values for their children in math. Therefore, it is possible that high math anxious parents may avoid doing math with their children because they lack math self-efficacy – that is, they do not have a firm grasp of what appropriate mathematics looks like for their young children and/or they lack the confidence to do math with their children. Thus, providing parents with a scripted, scaffolded, and low-pressure way to interact with their children around math, may help boost their ability to interact with their children around math, leading to gains in their children's math achievement. The following study investigates this possibility.

4. CHAPTER FOUR Study 3: Supporting Math Anxious Parents in Their Math

Involvement at Home

Studies 1 and 2 established that there are differences in the way that high and low math anxious parents relate to their children around math. High math anxious parents engage their children in less frequent and lower quality number talk when they are very young, engage their children in math activities at home less frequently, and hold lower expectations and values of math for their children. Additionally, parents' math anxiety is indirectly related to children's math knowledge as children are entering preschool and kindergarten. Therefore, it is possible parents' math anxiety will continue impact parent involvement, while also having an impact on student achievement throughout elementary school. The current study explores how parent math anxiety relates to student achievement and whether an intervention, in the form of an iPad app designed to foster parent-child engagement with math, can promote math learning over the course of a school year.

4.1. Background¹

For many families, stories are a regular part of a child's home routine. Parents are motivated to read to their children because they believe this activity promotes children's school achievement. However, they pay much less attention to supporting their children's math learning at home.

A widely held belief among parents is that children's math education is primarily the responsibility of schools, and that their role in supporting their children's math learning is not as

¹ The work reflected in this chapter has previously been published (Berkowitz et al., 2015; 2016). The original published manuscripts can be found here: <http://science.sciencemag.org/content/350/6257/196.full> and <http://science.sciencemag.org/content/351/6278/1161.3.full>

important as their role in supporting their children's reading (Cannon & Ginsburg, 2008). This belief is reinforced by messages conveyed through the media and schools, which predominantly focus on the need for parents to interact with their children around language and reading (Duursma et al., 2008). Unfortunately, the notion that math education is the purview only of schools and not also of parents ignores the fact that math input in the home is an important predictor of children's mathematical success (e.g., Levine et al., 2010). Here we demonstrate that a parent-child interactive math app, derived from psychological theories that emphasize the importance of parent involvement in children's learning (Tekin, 2011), increases 1st grade students' math achievement. Given the increasing prominence of tablet-style devices and internet access (Zickuhr, 2013), this intervention has the potential to be a low-cost, high-benefit method to ensure that parents' uneasiness with math does not translate into their children's low math achievement (Maloney et al., 2015).

Although there is an inherited component to math and spatial thinking (Butterworth, Varma, & Laurillard, 2011), experiences, including the math talk young children hear from their parents, are also implicated in children's math achievement. The amount of number talk parents engage in with their preschool children predicts 4- and 5-year-old's grasp of foundational number concepts (Gunderson & Levine, 2011; Levine et al., 2010). The frequency with which parents talk about shape and spatial features of objects—using words like circle, tall, edge, corner—also predicts children's spatial thinking (an important component of mathematical success) as they enter kindergarten (Levine, Ratliff, Cannon, & Huttenlocher, 2012; Pruden, Levine, & Huttenlocher, 2011; Verdine et al., 2014).

If parent math talk is important for children's mathematical success, then adding opportunities for parents and their children to discuss numerical and spatial aspects of math

throughout the school year should enhance children's math achievement. It might seem unlikely that a few additional opportunities for math-related talk per week would affect children's math achievement. However, many adults are apprehensive about math, reflected as math anxiety, and tend to avoid math whenever possible (Ashcraft, 2002; Hembree, 1990). Moreover, highly math-anxious parents provide a low quality of math input in the home (Studies 1 and 2; Eason et al., under review; Maloney et al., 2015). Therefore, even a modest increase in high-quality parent-child math talk could boost their children's math achievement.

In this study, parents and children were given access to either a math- or reading-related iPad app, 'Bedtime Learning Together'. If using the math app bolsters children's math achievement because it facilitates parent/child interactions around math, then children whose parents have the most math anxiety and provide lower quality math input at home should benefit the most from using the math app. Moreover, if parents' math anxiety is linked to variations in how much children grow in math achievement across the school year, then using the math app should decrease or eliminate differences in math achievement between children with low-math-anxious parents and children with high-math-anxious parents. Obtaining this latter result would highlight the importance of introducing support to promote parent-child math activities at home to ensure that all children (regardless of their parents' level of anxiety and comfort with math) have the opportunity to maximally achieve in math across the school year.

4.2. Methods

Participants

Children (N = 587; 287 males, 300 females) and their families were recruited from 22 schools across the Chicagoland area. 69.4% of the sample was from middle- to upper-middle class families, living in households making over \$50,000 per year. Children ranged in age from

53 to 92 months, with an average age of 78.5 months. 83.9% of parents who filled out the primary caregiver survey were the child's mother (children's fathers made up 14.8% of survey respondents; the remaining 1.3% of respondents were grandparents or aunts/uncles).

Procedure

Families were recruited through schools where principals and 1st grade teachers agreed to participate in the study. We recruited schools throughout the Chicagoland area, including public, private and parochial schools. Research assistants attended back-to-school nights to inform parents about the study and to distribute consent forms. Information about family income, race, education level, and size were collected with the original consent form.

Families were randomly assigned to a math group (420 families) or reading (control) group (167 families) with our main focus, the math group, oversampled. Children were assigned to group at the classroom level because parents often talk to each other within classrooms, and we wanted to minimize the chances that (a) families would become aware of the multiple treatment groups and (b) that families would ask to change conditions. In schools where there was only one 1st grade classroom, all students were assigned to the math group. In schools with two or more 1st grade classrooms, one classroom was randomly assigned to the reading group and the remaining classrooms were assigned to the math group. In all, students were spread among 40 classrooms and 22 schools.

Children were tested during two half-hour sessions in both the fall and the spring of the 2013-14 school year, as the first year of a larger, 5-year longitudinal study. Children were tested in a one-on-one session by one of eight trained researchers (two post-docs, two graduate students and four full-time research assistants made up the team of testers). At testing, researchers were

blind to the group the classroom was assigned to and had no knowledge of parents' math anxiety levels.

The first session at both the beginning and end of the school year consisted of several different achievement measures. In the current study, we focus on the Woodcock-Johnson-III Applied Problems Subtest and the Woodcock-Johnson-III Letter-Word Identification Subtest, nationally normed measures of math and reading achievement, respectively (Woodcock, McGrew & Mather, 2001). The second session consisted of several different academic attitude measures. Once student testing was completed at the beginning of the school year, parents were given the iPad Mini along with a survey to fill out and mail back.

Child Measures.

Woodcock-Johnson III Applied Problems subtest. As a measure of math performance, we administered the WJ III Applied Problems subtest, a subtest on a nationally normed, comprehensive test battery used to assess achievement skills of individuals between the ages of 2 through 90 years. The test consists of orally presented word problems that involve arithmetic calculations of increasing difficulty. For example, early problems involve single-digit arithmetic, while later problems involve money calculations and simple fractions. Form A of the test was used in the fall testing session, and Form B was used in the spring. Testing continued until basal (six items correct in a row) and ceiling (six items incorrect in a row) were established. 34 children were excluded from math analyses due to experimenter error leading to failure to achieve either a basal or ceiling on this subtest (24 in the fall: 16 in the math app group, 8 in the reading app group; 10 in the spring: 9 math app group, 1 reading app group).

Woodcock-Johnson III Letter-Word Identification. As a measure of reading we administered the WJ III Letter-Word Identification subtest, which measures the ability to identify

letters and decode words at increasing levels of difficulty. It is administered using the same basal and ceiling criteria as the Applied Problems subtest, and again Form A was used in the fall and Form B in the spring. 25 children were excluded from reading analyses due to experimenter error leading to failure to achieve either a basal or ceiling on this subtest (7 in the fall: 4 math app group, 3 reading app group; 18 in the spring: 12 math app group, 6 reading app group).

All analyses for both the WJ Applied Problems and Letter-Word Identification subtests were performed on students' *W* scores, a transformation of the students' raw score into a Rasch-scaled score with equal intervals (a score of 500 is the approximate average performance of a 10-year-old). Because of its properties as an interval scale with a constant metric, the *W* score is recommended for use in studies of individual growth. However, for ease of interpretation and illustrative purposes in the figures, we used grade equivalent growth scores, a measure of how many months of knowledge children gained across the school year.

Parent Measures.

Parents were given a survey to fill out and mail back when they received the iPad Mini at the beginning of the school year. Parents were provided with a stamped envelope to return their survey. Families who did not return the survey were reminded multiple times via email to complete the survey. In total, 328 parents in the math group (83%) and 119 parents in the reading group (85.6%) returned the surveys. Response rates were approximately equal and high across groups thus we assume that the missing surveys are random (i.e. it is not the case that high-math anxious parents in one group would be less likely to complete the survey).

As in Studies 1 and 2, parent math anxiety was assessed using the sMARS (Alexander & Martray, 1989; Appendix A). Parent math anxiety in the math group ranged from 1 to 4.8, with a mean of 2.20 ($SD = .81$), and parent math anxiety in the reading group ranged from 1-4.8 with a

mean of 2.12 ($SD = .77$). Parent math anxiety was not correlated with average app use in either the math group ($r = -.07, p = .12$) or the reading group ($r = -.01, p = .91$).

Ipad App.

After their children were tested in the fall, parents were given an iPad mini with the Bedtime Learning Together ('BLT') app preloaded onto it. The math version of BLT is based on "Bedtime Math," an app created and distributed by the Overdeck Family Foundation and is available for free on iTunes and on the Android Market. The BLT app differs from the Bedtime Math app in the following ways. First, passage language was adapted to reflect the current year (e.g., a question might read, "If X was discovered in 1956, and it is now 2013, how many years ago was X discovered?" and the question and answer would be updated to say 2014 to reflect that BLT participants received the passage in 2014). Second, the questions used for the "Wee Ones" level were adapted so that all numbers used fell in the 0-10 range, so as to ensure that the lowest level question was developmentally appropriate for a preschool or kindergarten-aged child. Third, the passages were occasionally self-referential to Bedtime Math, and so all such references were removed from the BLT version of the app. Finally, the BLT version of the app was personalized to the specific family using it, so that each time the app was opened, parents could select which children were present at the time of usage. This ensured that we would know when the target child was present during app use, but also allowed parents to use the app with other children in the household.

Families were asked to use the app before bed with their children (or whenever worked best for them during their daily routine), preferably 4 times per week. Daily math (or reading) passages and questions were delivered to the families via the app in the afternoon each day.

Additionally, a bank of extra problems was always available for use. Importantly, delivering passages via an iPad allowed us to track how often parents used the app with their children.

For both the math and reading groups, each passage had five questions that differed in difficulty from the kindergarten/first-grade level to the fifth-grade level. The levels were called “Wee Ones,” “Little Kids,” “Little Kids Bonus,” “Big Kids,” and “Big Kids Bonus.” Questions in the math version of the app covered topics that included counting skills, basic arithmetic (addition, subtraction, multiplication and division), fractions, geometry, and patterns. Questions in the reading version of the app dealt with recalling facts from the story, vocabulary skills, spelling, and making inferences from information in the passages. In both groups, the questions at each level attempted to align with the specific goals set forth in the Common Core Curriculum for the corresponding grade level. For sample passages and questions for the math and reading groups, see Appendix C.

App Use. App use was calculated by dividing the total number of times families used the BLT app between fall and spring testing by the number of weeks families had access to the app. Weeks of access ranged from 21 to 30 (Mean = 25.43, $SD = 1.97$) for the math group and 21 to 27 (Mean = 25.26, $SD = 1.69$) for the reading group. For example, if a family had access to the app for 22 weeks between fall and spring testing, and used the app 88 times during this period, their average app usage would be 4 times/week. In this way, we were able to obtain a measure of how often, on average, children were exposed to the app. App use in the math group ranged from 0 to 4.30 times/week (Mean = 1.19, $SD = 0.97$ times/week). App use in the reading group ranged from 0 to 6.28 times/week (Mean = 1.61, $SD = 1.35$ times/week).

4.3. Results

All analyses were conducted using Hierarchical Linear Modeling (Raudenbush, Bryk, & Congdon, 2004) to account for the nesting of students within classrooms. Our analyses focus on students in schools that had at least one classroom assigned to the math group and one classroom assigned to the reading group ($n_{\text{math}} = 226$ families; $n_{\text{reading}} = 167$ families). Matching students in this way allows us to compare math and reading families sample from the same schools.

Children's Math Achievement

Relation Between Parents' Math Anxiety and Children's Math Achievement. We first conducted an "Intent-to-Treat" analysis on fall (or beginning-of-year) achievement scores, to ensure that there were no differences between groups at the beginning of the school year (see Table 17). We also expected the math achievement of children with high-math-anxious parents to be more affected by use of the math (versus reading) app because these children would not generally be provided with high quality math input at home. Therefore, we separated parents on the basis of whether they were lower or higher in math anxiety (median split). For children of high math anxious parents, we found no significant difference in fall math achievement between children in the math and reading groups [$\hat{\beta}_{11} = 2.27, t = 0.78, p = 0.44$]. Similarly, for children with low math anxious parents, we found no difference in fall math achievement for children in the math and reading groups [$\hat{\beta}_{21} = 2.39, t = 0.60, p = 0.03$].

Table 17. Relation of parent math anxiety to student math performance in math and reading groups.

Outcome:	WJ Applied Problems Spring '14	WJ Applied Problems Fall '13	WJ Letter-Word ID Spring '14
Fixed Effects			
Fall W Score	0.87*** (0.06)	---	0.69*** (0.03)
High Math Anxiety ⁺	470.01*** (1.96)	457.93*** (2.12)	468.38*** (2.060)
High Math Anxiety x Group	5.25* (2.64)	2.27 (2.92)	-0.32 (2.76)
Low Math Anxiety ⁺	475.10*** (1.04)	458.02*** (2.74)	470.62*** (1.80)
Low Math Anxiety x Group	-0.61 (2.23)	2.39 (4.01)	0.35 (2.48)

Numbers in parentheses are SEs

⁺Only includes participants for whom we have parent math anxiety measures.

*** $P < 0.001$, * $P < 0.05$

We then performed an “Intent-To-Treat” analysis in which we looked at the impact of group (math vs. reading app) on children’s end-of-year math achievement (controlling for beginning-of-year math achievement) independent of actual app usage (see Table 17). An Intent-To-Treat analysis allows us to rule out factors possibly related to app usage – such as motivation or interest – as explaining our findings. For children of high-math-anxious parents, we found a significant effect of group with children in the math group outperforming those in the reading group by almost three months in math achievement by school year’s end [$\hat{\beta}_{21} = 5.25, t = 1.99, p = 0.048$]. We did not find this same pattern for children of low-math-anxious parents [$\hat{\beta}_{31} = -0.61, t = -0.27, p = 0.79$] (see Figure 7). Even though comparing the coefficients of intent-to-treat effects for children of high- and low-math-anxious parents (i.e., the interaction between parent-math-anxiety and app condition) is a low-powered test, especially in field trials (Manski, 2005; McClelland & Judd, 1993), we see a marginally significant difference between the coefficients estimating the effects of the math app for these two groups of children at $p = 0.06$ (significant at $p = 0.03$ using a one-tailed test given our a priori hypothesis).

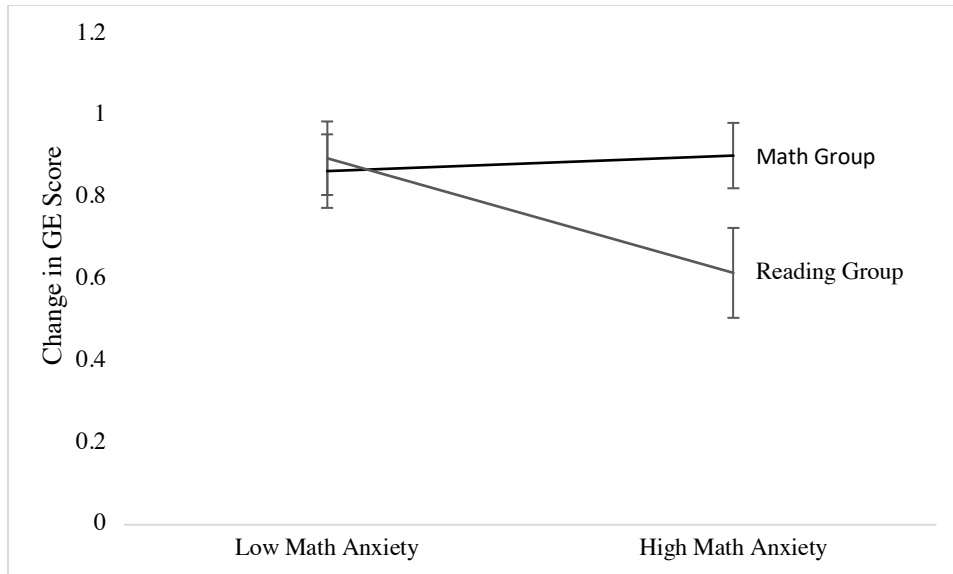


Figure 7. Student growth in math achievement by group and parents' math anxiety level. A change in Grade Equivalent (GE) score of 1 is equivalent to one school-year of learning. Students of high math anxious parents in the math group learned as much math over the course of the school year as their peers of low math anxious parents (in both the math and reading group). Those students with high math anxious parents in the reading group learned less math over the course of the school year than their peers.

The ITT analysis under-estimates the impact of using the app as it does not take app use into account. We can obtain an unbiased estimate of the impact of app use by using randomization as an instrumental variable (IV) to identify the impact of actual app use. We conducted an IV analysis on end-of-year math achievement (controlling for beginning-of-year math achievement), which estimates the effect of dosage on those whose dosage was induced by randomization (see Table 18). As in the ITT analysis, we obtained a significant effect of math app use on children of high-math-anxious parents [$\hat{\beta}_{21} = 4.12, t = 2.16, p = 0.03$], but no significant effect of math app use on children of low-math anxious parents [$\hat{\beta}_{31} = -0.65, t = -0.42, p = 0.67$]. This analysis suggests that there is a causal effect of math app usage on end-of-year math achievement for the children of high-math-anxious parents and that this effect is negligibly influenced by selection bias.

Table 18. Instrumental Variable Analysis

Outcome:	WJ Applied Problems Spring '14
Fixed Effects	
Fall W Score	0.86*** (0.06)
High Math Anxiety	471.34*** (1.47)
Low Math Anxiety	476.86*** (1.06)
High Math Anxious x estimated dosage	4.12* (1.92)
Low Math Anxious x estimated dosage	-0.65 (1.54)

Numbers in parentheses are SEs

*** $P < 0.001$, * $P < 0.05$

Last, we ran a regression taking into account children’s frequency of app use. The more times parents and their children used the app (ranging from 0 to 6.28 times/week), the higher children’s math achievement at school year’s end (controlling for beginning-of-year math achievement), but only for children in the math group as shown by a group x use interaction on end-of-year math achievement [$\hat{\beta}_{21} = 4.03, t = 2.83, p = 0.005$](see Table 19). This interaction demonstrates that it’s not any engagement with parents around academic content that increases children’s math achievement, but engagement with math specifically.

Table 19. Effect of app use on student achievement by group.

Outcome:	WJ Applied Problems Spring '14
Fixed Effects	
Group	474.25*** (1.98)
Fall W Score	0.79*** (0.06)
Average App Use	0.23 (0.900)
Group x App Use	4.03* (1.42)

Numbers in parentheses are SEs

*** $P < 0.001$, * $P < 0.05$

Children’s Reading Achievement

In addition to looking at changes in performance on the WJ Math Applied Problems subtest as a function of app use, we also looked at how app usage in the math and reading groups influenced achievement on the WJ III Letter-Word Identification subtest. We performed a second “Intent-to-Treat” analysis in which we looked at the impact of condition (math vs.

reading app) on children's end-of-year reading achievement (controlling for beginning-of-year reading achievement) independent of actual app usage, separating parents on the basis of whether they were lower or higher in math anxiety (see Table 17). We did not find a significant effect of condition for children of high-math anxious parents [$\hat{\beta}_{21} = -0.32, t = -0.12, p = 0.91$], or for children of low-math anxious parents [$\hat{\beta}_{31} = 0.35, t = 0.14, p = 0.89$] (see Figure 8).

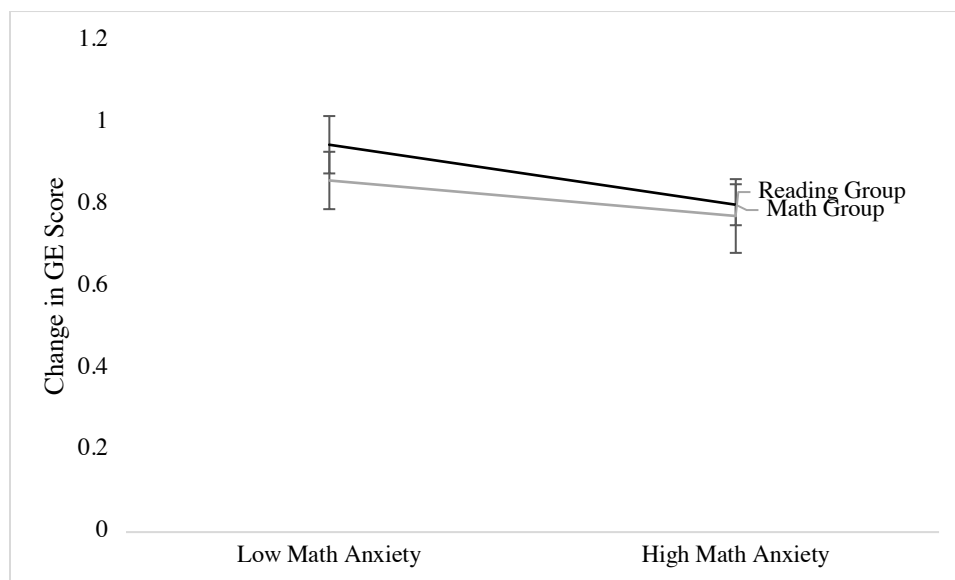


Figure 8. Student growth in reading achievement by group and parents' math anxiety level. All students, regardless of group assignment and parent math anxiety level made equal gains in performance on our measure of reading achievement.

It is perhaps not surprising that being assigned to the reading group did not affect children's gains in Letter-Word Identification across the school year given that many parents are already doing reading related activities with their children at home, and that this subtest measures decoding. Additionally, given that the math app is verbal in nature, and similar reading passage content was used in the reading and math apps, enhancements to reading comprehension (e.g., through opportunities to learn new vocabulary) was likely similar across the math and reading apps, although this was not tested in the current study.

4.4. Discussion

Studies 1 and 2 demonstrated that math anxious parents tend to avoid engaging their children in math-related activities outside of school. Unfortunately, limited exposure to math translates to poor performance in math. The present study found that providing families with a math-related iPad app to use together at home helped ameliorate the negative relation between parent math anxiety and student achievement. Students of math anxious parents who were assigned to the math group made gains in math learning that were equivalent to those of their peers with low math anxious parents. However, students of high math anxious parents in our reading control group made smaller gains in math learning over the course of the school year than their peers.

Parents may also be unwittingly transmitting their negative attitudes about math to their children, further handicapping their children's achievement. However, when parents and children interact around math story problems, children show increased math achievement by the end of a school year. The benefits of occasional math-related interactions are especially apparent for children whose parents are anxious about math. By providing an engaging way for math anxious parents to share math with their children, the math app may help cut the link between parents' high math anxiety and children's low math achievement.

5. CHAPTER FIVE: General Discussion

Gaps in children's math knowledge are present before children enter kindergarten (e.g., Clements & Sarama, 2007; Klibanoff et al., 2006) and these gaps tend to persist throughout elementary, middle and high school (Duncan et al., 2007). Previous research has demonstrated that variation in the quantity and quality of parents' number talk plays a large role in children's early math development (e.g., Huttenlocher et al., 2002; Levine et al., 2010), suggesting that promoting parent math-engagement with their children at home could help eliminate these early achievement gaps. Several factors, including socio-economic background and parents' math ability, have been implicated as playing a role in the variation of parent-child math engagement that occurs at home (e.g., Elliot, Braham, and Libertus, 2017; Jordan et al. 1994; 2006).

However, simply increasing the quantity of math input that children receive at home may not be sufficient to promote math learning, as research has also shown that parents' negative attitudes towards math impact the quantity, and even more importantly, the quality of parent-child math interactions at home during elementary school, so that not all parent-child interactions are beneficial (e.g., Hyde et al., 2006; Maloney et al., 2015). Despite the importance of early math input prior to starting kindergarten, little work has considered how parents' math attitudes impact the math interactions parents have with their children before children enter elementary school.

This thesis explores the role that one such attitude – math anxiety – plays in shaping children's early math learning. Specifically, we looked for evidence that parents' math anxiety is negatively related to the exposure that children receive to talk about numbers and math activities at home prior to starting formal schooling, and that this negative relation is associated with poorer math outcomes for their children.

The present set of studies demonstrates that parents' math anxiety does relate to parent-child math engagement at home, as well as to children's math knowledge upon entering school. The results described in Studies 1 and 2, as well as Eason et al. (under review), indicate that parents' math anxiety is associated with parents engaging in math-related talk and activities less frequently with their children than their non-math anxious peers. Study 2 also provides some preliminary evidence that parent math anxiety is related to children's math knowledge at the start of school. Finally, Study 3 demonstrates that while parent math anxiety is related to lower performance on an assessment of math ability at the start of school, an intervention that supports parents in their math-related interactions with their children can ameliorate the negative impact of parents' math anxiety on student achievement. In this chapter, I summarize the findings of Studies 1-3, outline plans for future research, and ultimately discuss the broader impacts of this work.

5.1. Summary of Results

Studies 1 and 2 explored the relation of parent math input to parent math anxiety when children were between 1 to 5 years of age. In Study 1, we found that parents' math anxiety was negatively related to the overall quantity of parent number talk that children heard at home, and that this relation was specific to children from higher-SES backgrounds who generally hear more talk at home. Moreover, parent math anxiety related to the quality of parent number talk – math anxious parents provided fewer instances of labeling the cardinal values of sets for their children and talked less about objects that are present than their non-math anxious peers. This is some of the first evidence that parent math anxiety impacts even the most basic and preliminary math input that children receive at home.

Study 2 then demonstrated that parent math anxiety was related to parents' math involvement with their children as their children were transitioning into school, even when controlling for SES. Math anxious parents reported that they (1) hold lower expectations and values of math for their children and (2) engage their children in math-related activities at home less frequently than their non-math anxious peers. Additionally, this relation was mediated by parents' math self-efficacy. Parents' math anxiety was negatively related to parents' confidence in their ability to help their children learn math, and this in turn was related to the frequency of math input children received at home. Furthermore, we found an indirect effect of parents' math anxiety on students' math knowledge when they entered school, as well as a direct relation of parents' expectations and values of math for their children on student performance on a math assessment. Finally, Study 2 also found that parents' math anxiety led to variation in their number talk when playing with a toy that invited, but did not necessitate, talk about math. However, there was some evidence that providing a small cue to parents that they should talk about numbers while playing with this toy helped mitigate this relation.

We then turned to explore whether an intervention, designed to foster parent-child math engagement at home, could help student achievement in early elementary school. In Study 3, we found that children of math anxious parents who received a math related app to use with their parents made gains in math that did not significantly differ from their peers with low math anxious parents. In contrast, children of high math anxious parents in a reading control group did not learn as much math over the course of the school year. This suggests that providing parents with a low-pressure and scripted way to interact with their children around math can have a positive impact on student learning in school.

5.2. Limitations and Future Directions

This dissertation is just a starting point in exploring how particular parent characteristics impact a parents tendency and ability to interact with their young children around math. Here we focused specifically on math anxiety and the way it impacts parent-child engagement specifically around activities related to numbers, but as discussed previously, there are a multitude of other parent background characteristics, such as their SES and math knowledge, that also influence parent engagement with math (e.g., Elliott et al., 2017; Jordan et al., 1994). Future research should continue to explore the impact of all of these factors in conjunction with one another to develop a deeper understanding of the barriers parents face to interacting with their children around math. For example, Study 1 found an interaction between parent math anxiety and SES such that math anxiety was only significantly related to parent math talk for higher-SES parents. This does not mean that math anxiety is only a significant issue for high SES individuals. Rather, this interaction is likely a result of there being fewer instances of number talk among lower-SES parents, making it difficult to detect a similar impact of math anxiety in this population. Therefore, interventions targeted at increasing math talk in lower-SES communities should still be sensitive to those parents who may be math anxious and need extra support to engage in effective math talk with their children. Furthermore, future work should explore other potential barriers, e.g., cultural beliefs and gender and racial stereotypes, that prevent parents from engaging their children in math, with the goal of understanding what types of supports will enable all parents to become involved in their children's math education.

Future research should also look at whether the relation of math anxiety to the frequency and quality of math interactions differs by type of activity. Here, we looked at how parent math anxiety related to the frequency of broadly defined math-related activities (e.g., frequency of

exposure to math related TV and video games, or frequency of exposure to math workbooks). However, previous research has drawn a distinction between formal (or direct) math activities, such as counting and simple arithmetic, and informal (or indirect) math activities, such as connect-the-dot games or playing “store” (LeFevre, et al., 2009; Purpera, et al. 2017; Skwarchuk et al., 2014). It may be that math anxiety causes parents to avoid formal math activities and not informal math activities. Indeed, Studies 1 and 2 suggest that math anxious parents are talking less to their children about math during both everyday activities and activities that invite talk about numbers. Additionally, even when they do engage in these different math activities, the quality of the math interactions likely varies with parent math anxiety levels. Since informal math activities typically lack guidelines demonstrating how to incorporate meaningful math talk into the activity, it would be interesting to explore whether math anxious parents provide lower quality input (or no math input) during informal, but not formal, math activities.

This dissertation focuses specifically on math anxiety and math input as it relates to numbers. However, there are other aspects of early math input that are also important to children’s math development and learning. For example, studies with both children and adults demonstrate that spatial skills are highly correlated with math skills and may contribute to children’s math development (e.g., Mix et al., 2016; Wai, Lubinski, & Benbow, 2009). Just as parent number talk is related to early number knowledge, parent talk that incorporates spatial words (shapes: e.g., circle, triangle, square; sizes: e.g., tall, short, small; and features: e.g., curved, straight, corner) is related to children’s spatial ability (Pruden et al., 2011; Verdine et al., 2014). Future research should look at the influence of both math anxiety and spatial anxiety on broader aspects of math. Some initial work looking at the intergenerational impacts of spatial anxiety has found evidence that adults’ spatial anxiety influences children’s performance on

spatial tasks (Gunderson, Ramirez, Beilock, & Levine, 2013). They found that students' spatial skills at the end of the school year were negatively related to teachers' spatial anxiety, even when controlling for teachers' math anxiety. Since spatial skills are an important component of math and other STEM-areas (Gunderson, Wai, Lubinski, & Benbow, 2009), further study of the negative impacts of adults' spatial anxiety on children's spatial ability is an important area for future research.

Future research should also take a deeper look into how the kind of number talk a parent engages in varies with their math anxiety, e.g., counting, cardinal labeling of sets, time, measurement, etc. Previous work has found that the best type of number talk for early learning combines both counting and labeling of cardinal sets (Mix et al., 2012). It would be interesting to see whether parents are engaging in number talk that incorporates both types of number talk concurrently (e.g., "There are three apples. One, two, three.") and if the tendency to do so varies with parent math anxiety.

This dissertation also limits the definition of quality of number talk to focus on the richness of parents' talk about numbers. However, the quality of parent-child interactions can also vary based on other characteristics, such as the feedback a parent provides during the interaction, the parents' level of engagement throughout an interaction, etc., and their tendency to actively engage children in mathematical thinking by asking questions. Future work should explore whether math anxious parents are more intrusive during math-related interactions than non-math anxious parents (i.e. cutting off the child while speaking, providing the child with fewer opportunities to answer questions, etc.) or if math anxious parents simply engage less with their child throughout the math activity.

Last, this dissertation tested an intervention in the form of a math-related iPad app intended to support parent-child interactions at home. The success of our intervention begs the question of whether the results persist beyond one year. Indeed, follow-up work with the students in this study found that the effects of our intervention persisted at least through the end of 3rd grade (see Figure 8), even though most families stop using the app at the end of the first year (Schaeffer et al., under review). Furthermore, we found that the sustained benefit of the math app intervention is related to increases in the expectations and values of math that high math anxious parents hold for their children (Schaeffer et al., under review).

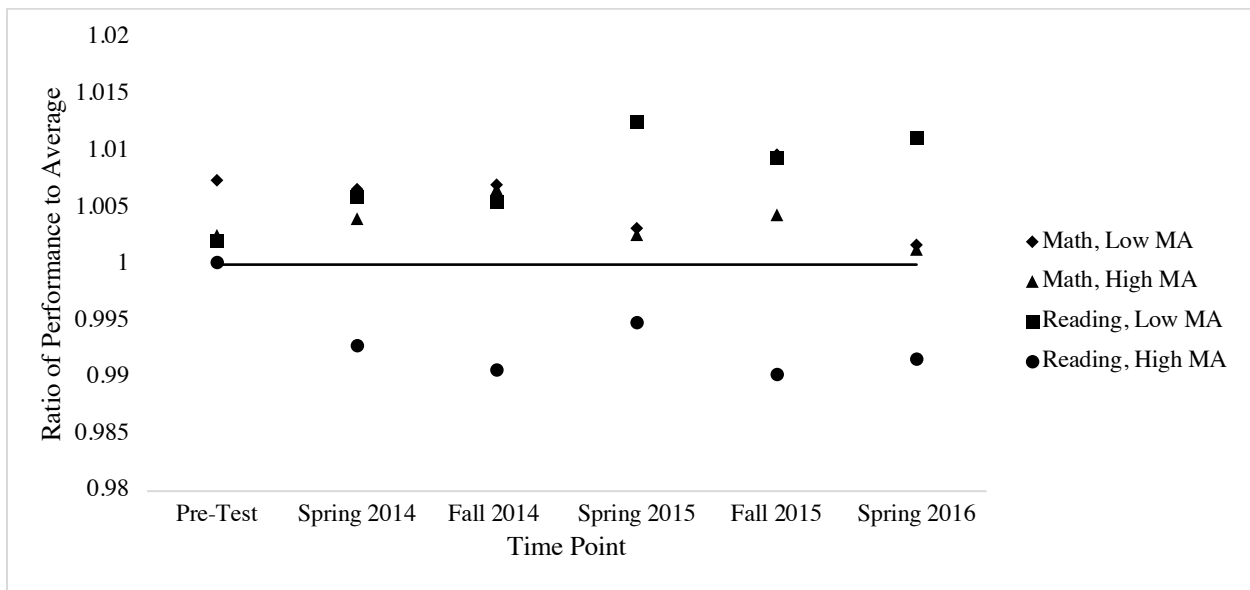


Figure 8. Ratio of student performance on math assessment to overall average by group and parent math anxiety level over the course of 3 years. Students in the reading (control) group with high math anxious parents consistently perform below average (when compared with students in the reading group of low math anxious parents, or all students in the math group).

Future work should also take a closer look at how parents' math self-efficacy relates to parent math anxiety, their expectations and values of math for their children and student math achievement. This dissertation found that the relation of parent math anxiety to parent engagement in math during the transition to preschool or kindergarten is mediated by parents' math self-efficacy. Here we used parents' confidence in their ability to help their children with

math homework as a measure of self-efficacy, but future work should explore the relation of self-efficacy to math anxiety and math engagement more thoroughly. Additionally, Study 2 and previous work (e.g., Hoover-Dempsey et al., 2001, 2005) suggest that self-efficacy plays a role in parents' decisions to get involved in their children's education, and likely also impacts their decision to comply with the math intervention. Future work should explore whether an intervention like the app tested here can help boost parents' self-efficacy, which would hopefully translate into parents feeling better equipped to engage in other math activities with their child. Finally, the intervention tested here was carried out with a sample that was primarily from middle- to high-SES backgrounds. If interventions are only effective or taken up among higher-SES populations, then we may be inadvertently contributing to increases in achievement gaps (Ceci & Papierno, 2005). Therefore, future work should look at the impact of a similar intervention in a low-SES population.

5.3. Conclusion: Contributions and Practical Implications

The present studies make several important contributions to the existing literature on the variation in parent math input and the development of interventions to increase parent-child math engagement. First, these studies highlight the influence of parents' negative feelings about math, measured here through math anxiety, on the exposure to math that children receive at home. Second, these studies demonstrate that parent math anxiety influences parent-child math engagement throughout children's early math development, starting as early as when children are 14-30 months of age, and that by the time children start kindergarten, parent math anxiety is negatively impacting student math knowledge. Third, these studies demonstrate that providing simple math supports to parents can help mitigate the relation of parent math anxiety to parent engagement with math, and as a result improve child achievement in math in later years,

suggesting that thoughtful interventions can be successful in preventing the emergence of achievement gaps related to parents' math anxiety.

This dissertation suggests one avenue to supporting parent-child math interactions, via an app on a tablet device. However, as computers and smartphones become a staple in every household, websites can be an effective way to teach parents how to talk about math and use numbers in everyday activities with their children. Additionally, other media such as books, games, and community events (e.g., math night at a local library or school) also provide great opportunities to give parents the extra support they need to talk to their children about basic math concepts.

We know that, in general, parental involvement and engagement is an important avenue to promote children's academic achievement. However, interventions, especially those related to numeracy, are generally aimed at increasing parent involvement in education, with the assumption that all parents are equally capable of having high quality parent-child math interactions with their children. This dissertation asked how a parent-specific characteristic influences parents' tendency and ability to effectively promote children's math achievement and explored one avenue to help foster positive and effective parent-child math interactions. The findings highlight that while some parents may naturally choose not to engage in their children's math learning, when provided with sufficient support we can improve parent-child math interactions and have a positive influence on children's math achievement. By intervening early on to prevent the formation of achievement gaps related to parents' math anxiety, we can break the vicious cycle of poorly performing math students who then turn into math anxious parents with children of their own.

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Appendix A: Measure of Parent Math Anxiety (sMARS; Alexander & Martray, 1989) and Parent Reading Anxiety

Instructions: Imagine you are in school. The items in this questionnaire refer to things and experiences that may cause tension, apprehension, or anxiety. For each item, circle the number that corresponds to the response that describes how much the situation described would make you feel anxious. Work quickly, but be sure to think about each item.

Math Anxiety:

	<i>Not at all</i>	<i>A little</i>	<i>A fair amount</i>	<i>Much</i>	<i>Very much</i>
1. Receiving a math textbook.	1	2	3	4	5
2. Watching a teacher work an algebra problem on the blackboard.	1	2	3	4	5
3. Signing up for a math course.	1	2	3	4	5
4. Listening to another student explain a math formula.	1	2	3	4	5
5. Walking to math class.	1	2	3	4	5
6. Studying for a math test.	1	2	3	4	5
7. Taking the math section of a standardized test, like an achievement test.	1	2	3	4	5
8. Reading a cash register receipt after you buy something.	1	2	3	4	5
9. Taking an examination (quiz) in a math course.	1	2	3	4	5
10. Taking an examination (final) in a math course.	1	2	3	4	5
11. Being given a set of addition problems to solve on paper.	1	2	3	4	5
12. Being given a set of subtraction problems to solve on paper.	1	2	3	4	5
13. Being given a set of multiplication problems to solve on paper.	1	2	3	4	5
14. Being given a set of division problems to solve on paper.	1	2	3	4	5
15. Picking up your math textbook to begin working on a homework assignment.	1	2	3	4	5
16. Being given a homework assignment of many difficult math problems, which is due the next time the class meets.	1	2	3	4	5
17. Thinking about an upcoming math test one week before.	1	2	3	4	5
18. Thinking about an upcoming math test one day before.	1	2	3	4	5
19. Thinking about an upcoming math test one hour before.	1	2	3	4	5
20. Realizing that you have to take a certain number of math classes to meet the requirements for graduation.	1	2	3	4	5
21. Picking up a math textbook to begin a difficult reading assignment.	1	2	3	4	5

22. Receiving your final math grade on your report card.	1	2	3	4	5
23. Opening a math or statistics book and seeing a page full of problems.	1	2	3	4	5
24. Getting ready to study for a math test.	1	2	3	4	5
25. Being given a "pop" quiz in a math class.	1	2	3	4	5

Reading Anxiety (items marked with * are included in the abbreviated version used in Study 2):

	<i>Not at all</i>	<i>A little</i>	<i>A fair amount</i>	<i>Much</i>	<i>Very much</i>
*1. Receiving an English textbook.	1	2	3	4	5
2. Watching a teacher diagram a sentence on the blackboard.	1	2	3	4	5
3. Signing up for an English course.	1	2	3	4	5
4. Listening to another student explain the purpose of a work of literature.	1	2	3	4	5
5. Walking to English class.	1	2	3	4	5
*6. Studying for an English test.	1	2	3	4	5
7. Taking the verbal section of a standardized test, like an achievement test.	1	2	3	4	5
8. Reading an instruction manual.	1	2	3	4	5
*9. Taking an examination (quiz) in an English course.	1	2	3	4	5
10. Taking an examination (final) in an English course.	1	2	3	4	5
11. Being given a passage to edit.	1	2	3	4	5
*12. Being given a play to analyze.	1	2	3	4	5
13. Being given a poem to interpret.	1	2	3	4	5
14. Being given a sentence to diagram.	1	2	3	4	5
15. Picking up your English book to begin reading a story.	1	2	3	4	5
16. Being given a writing assignment analyzing a book, which is due the next time the class meets.	1	2	3	4	5
17. Thinking about an upcoming English test one week before.	1	2	3	4	5
*18. Thinking about an upcoming English test one day before.	1	2	3	4	5
19. Thinking about an upcoming English test one hour before.	1	2	3	4	5
20. Realizing that you have to take a certain number of English classes to meet the requirements for graduation.	1	2	3	4	5
21. Picking up an English book to begin a difficult reading assignment.	1	2	3	4	5

22. Receiving your final English grade on your report card.	1	2	3	4	5
23. Opening an English book and seeing a long story.	1	2	3	4	5
24. Getting ready to study for an English test.	1	2	3	4	5
25. Being given a "pop" quiz in an English class.	1	2	3	4	5

Appendix B: Parent Questionnaires

Parent math self-efficacy:

Directions: Please circle the number that corresponds to your answer for each question.

	<i>Not at all confident</i>	<i>Not confident</i>	<i>Moderately confident</i>	<i>Confident</i>	<i>Very confident</i>
1. How confident would you say you are in your ability to help your child with his/her math homework?	1	2	3	4	5
2. How confident would you say you are in your ability to help your child with his/her reading homework?	1	2	3	4	5

Frequency of engagement in math and reading activities at home:

Directions: Please circle the number that corresponds to your answer for each question.

	<i>Never</i>	<i>Once a month</i>	<i>Less than once a week</i>	<i>Once a week</i>	<i>2-3 times a week</i>	<i>Every day</i>	<i>More than once a day</i>
1. How often do you help your child with his/her math homework?	1	2	3	4	5	6	7
2. How often do you help your child with his/her reading homework?	1	2	3	4	5	6	7
3. How often do you expose your child to math through...							
a. Workbooks that involve math	1	2	3	4	5	6	7
b. Educational television shows, videos or DVDs that involve math	1	2	3	4	5	6	7
c. Educational computer or video games that involve math	1	2	3	4	5	6	7
d. Other educational toys and games that involve math	1	2	3	4	5	6	7
e. Other everyday activities that involve math, please list: _____	1	2	3	4	5	6	7
4. How often do you expose your child to reading through...							
a. Workbooks that involve reading	1	2	3	4	5	6	7
b. Educational television shows, videos or DVDs that involve reading	1	2	3	4	5	6	7
c. Educational computer or video games that involve reading	1	2	3	4	5	6	7
d. Other educational toys and games that involve reading	1	2	3	4	5	6	7
e. Other everyday activities that involve reading, please list: _____	1	2	3	4	5	6	7

Measure of Parents Expectations and Values in Math and Reading:

Parents were asked questions about their child’s ability in math (and reading) and their future expectations for their children in math (and reading; see questions below). These questions are based on measures used in previous work in this area (Wigfield & Cambria, 2010). Response options ranged from 1-5 with different anchors for each scale.

How well is your child doing in math / reading?	Not well at all	Not well	Moderate	Well	Very well
How much natural talent does your child have in math / reading?	None at all	A little	A fair amount	Much	Very much
How important do you think math /reading is for your child?	Not at all important	Slightly important	Moderately important	Important	Very important
How well do you think your child will do in math / reading in the future?	Not well at all	Not well	Moderate	Well	Very well

Appendix C: Sample BLT Math and Reading Passages with Questions.

Sample Math Passage and Questions:

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.

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.

Questions. Wee ones (counting on fingers): 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? Bonus: If when no one’s looking you slurp up 9 cups of the whipped cream, how much heavy cream did it take to make that? Big kids: If a can of whipped cream holds 6 cups, and when you open it, it kind of explodes and squirts $1\frac{1}{2}$ cups on you, how much is left in the can? Bonus: If you then try to squirt half of what’s left into your mouth, how much is left after that?

Answers: Wee ones: 4 cups of air. Little kids: 18 cups of whipped cream. Bonus: 3 cups of heavy cream (by the way, at 800 calories per cup, that’s 2400 calories - about as much food as a grown-up eats in a day. We don’t recommend eating that all at once). Big kids: $4\frac{1}{2}$ cups. Bonus: $2\frac{1}{4}$ cups left.

Sample Reading Passage and Questions:

Whipped cream was invented a long time ago, and is credited to a bunch of guys with long unpronounceable Italian and French names. But what made them think to whip up heavy 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.

Whipping air bubbles into heavy cream makes it take up a lot more “volume,” or space. In the Bedtime Learning Together test kitchen, just a little heavy cream generated a lot of fluffy whipped cream! With something as important as dessert, that’s a key fact!

Questions. Wee ones: How did people make whipped cream before we had electricity? Little Kids: What’s the difference between whipped cream and cream? Bonus: Which countries were the inventors of whipped cream from? Big Kids: How does whipping heavy cream turn it into whipped cream? Bonus: In the sentence, “In the Bedtime Learning Together test kitchen, just a little heavy cream generated a lot of fluffy whipped cream,” what does the word “generated” mean?

Answers: Wee Ones: It was whipped by hand. Little Kids: Whipped cream has air whipped into it so it is fluffier than cream. Bonus: France and Italy. Big Kids: The whipping process creates air bubbles. Bonus: To "generate" means to make or create.