Examining the Role of Children's Responsiveness When Studying the Impact of Parents' Use of Math Elicitations on Children's Math Performance

by

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When children start kindergarten, there are already individual differences in math ability (Aubrey, 1997; Sarama & Clements, 2009). These early differences have long-term effects that predict math achievement throughout later schooling and impact future career outcomes, including income (Bodovski & Farkas, 2007). One significant predictor of children's math performance is the quantity of parents' math input with their child. Previous studies have shown that the more parents talk about or engage in math-related activities with their children, the better their child tends to perform in math (Levine et al., 2010; Skwarchuk, 2009). These studies have focused on parents' overall math talk but have not looked at specific types of math talk. Here, I examine the frequency of parental use of math-related elicitations (questions and commands intended to evoke a response using math concepts) during a free play interaction with their preschool-aged child (140 parent-child dyads; child *M* age=3.91 years). In addition to looking at this parent factor, I also consider the child's level of math responsiveness (i.e., proportion of responses to parent math elicitations relevant to the math concept) and investigate whether more responsive children benefit more from parent math elicitations than less responsive children. I found that children who more frequently responded to their parents' math elicitations with relevant responses performed significantly better on the TEMA-3 (Baroody & Ginsburg, 2003), $\beta = .30$, $p < .001$, even when controlling for the overall frequency of relevant responses to parents' non-math elicitations. Contrary to my hypotheses, parental math elicitations did not have a significant effect on children's math achievement, nor did I find that children's responsiveness moderated this association. These findings suggest that children's own behavioral factors may play as important, if perhaps not more important, of a role as the social parental factors in math development. Parental math elicitations were not a significant predictor, which suggests that the quantity of math input may not matter as much as how the child responds to it. Thus, future work could examine interventions to increase children's attention and responsiveness to their parents, in the hopes of helping them benefit more from math input.

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Preface

I would like to give a special thanks to my faculty advisor, Dr. Melissa Libertus, and my graduate mentor, Alex Silver, for their support and guidance throughout the completion of my thesis. I'd also like to express my gratitude to my Bachelor of Philosophy honors thesis committee members for their feedback and time. Thank you also to the rest of the Kids' Thinking Lab for their assistance with transcribing and coding.

1.0 Introduction

Math is useful for many aspects of our daily life, from measuring fractions when following a recipe, to creating a budget plan for a vacation, to using geometric concepts while playing recreational sports. The ability to develop and apply mathematical thinking to everyday tasks is critical for success in our society. Thus, it is crucial for children to master the basic foundations of mathematics.

Unfortunately, we observe substantial variability in children's math ability, even at early ages. At the time of kindergarten entry, there are already individual differences in children's math performance (Aubrey, 1997; Sarama & Clements, 2009). Some children may already know how to solve basic addition or subtraction problems, while others may only be able to count to ten. These early differences in math skills have long-term effects that can predict math achievement throughout later schooling and can even impact future career outcomes (Bodovski & Farkas, 2007; Trusty et al., 2000). Math knowledge in children is predictive of their later math and reading competence, which are crucial skills for overall academic achievement (Watts, Duncan, Siegler, & Davis-Kean, 2014). For example, children placed in advanced ability groups in middle school, based on academic achievement, are more likely to meet prerequisites for advanced courses once they enter high school (Hoffer, 1992), and past work has found that enrollment in advanced high school math courses is significantly related to individuals' income a decade after graduation (Rose & Betts, 2004). Children who begin kindergarten with a weaker understanding of early math concepts are at a disadvantage which may ultimately limit their potential for future success in life. Therefore, it is critical for researchers to study the origins of this observed variability in early math ability with the goal of understanding how to better prepare and provide all children with an equally strong foundation of mathematics.

1.1 Home Math Environment

In an effort to understand what causes individual differences in children's math skills, abundant research has examined potential factors that may impact children's math ability before beginning formal schooling. For instance, this variability in formal math performance has been linked to children's domain-general and domain-specific cognitive factors (Libertus, Feigenson, & Halberda, 2013; Hart, Petrill, Thompson, & Plomin, 2009; Hyde, Khanum, & Spelke, 2014). Along with differences in cognition, differences in early math ability have also been attributed to various social and environmental factors. Thus, a growing number of studies have looked at parental involvement in home numeracy. Parental involvement in children's math learning has been found to benefit both children's achievement and attitude, however, there is limited evidence that interventions to enhance involvement actually result in better outcomes (Jay, Rose, and Simmons, 2017).

Importantly, the home learning environment can be shaped by parental education and family socioeconomic status. These factors can influence the amount of resources available in the home environment, including physical, financial resources as well as parents' psychological resources (see Duncan, Magnuson & Votruba-Drzal, 2014). Additionally, parents' math ability may also play a role. Dearing and colleagues (2012) found that mothers with higher education and better math ability participated in more math activities with their children, while mothers with less education and lower math ability tended to create less stimulating home math learning environments for their children. Previous research has also looked at how parents engage with their children and encourage math at home. This includes examining how frequently parent-child dyads engage in math-related activities at home, which can be activities like counting objects, playing board games, and measuring ingredients while baking. Findings suggest that the more parents engage in math-related activities with their children, the better their children's math performance (LeFevre et al., 2009; Skwarchuk, 2009).

Recent research has also focused specifically on parents' math talk, i.e., their discussion of numbers and math concepts. Many researchers have found a significant relation between the quantity of parental math talk and children's math performance (Levine et al., 2010; Ramani et al., 2015; Elliot, Braham & Libertus, 2017; Casey et al., 2018). More specifically, findings suggest that higher frequency of parent math talk leads to a greater understanding of number words (cardinal-number knowledge) in children (Levine et al., 2010). After exposure to parents who used more number talk in reference to larger quantities, ranging from 4-10, children displayed better cardinal-number knowledge for both small and large numbers compared to those who heard number talk about smaller quantities ranging from 1-3 (Gunderson & Levine, 2011). In another sample of 5- to 6-year-old children, researchers again found that parents' use of number talk about larger numbers was positively correlated with children's math performance, while number talk about smaller numbers was not significantly related to children's math performance (Elliott, Braham & Libertus, 2017). Together, these studies suggest that the quality of the parental math input is also important and that some types of math talk may be contributing to children's growth in math knowledge more than others.

Previous work has tended to focus specifically on parents' talk about numbers or has combined talk about all math concepts into one measure of overall parent math talk. However, there are potentially many different types of math talk. For instance, math talk can encompass discussion of cardinal numbers (e.g., labeling a set of “five apples”), ordinal numbers (discussing the order of numbers, e.g., “the third car”), shapes (e.g., “the circle”), sequence (discussing the order of events, e.g., “the next page”), patterns (discussing alternating items, e.g., “blue, red, blue, red”), orientations (describing relative spatial locations, e.g., “the left house”), and math elicitations (commands or questions intended to provoke a response using math concepts, e.g., asking “how many pears?”). Combining all of these categories together to examine overall math talk could miss important nuances because different types of math input may be contributing to children’s math performance more than others or in different ways.

1.2 Parent Questioning & Eliciting

No published work to date has looked specifically at the use of elicitations in promoting math learning. However, in domains other than math, work suggests that asking questions and eliciting responses from children may give parents the opportunity to guide their children’s attention to important points. Specifically, Sénéchal (1997) found that parents’ questioning and use of elicitations were related to children’s literacy development. Parents’ use of vocabulary eliciting questions (which require the child to use new vocabulary words) during joint storybook reading had beneficial effects on the child’s receptive and expressive vocabulary development. However, it remains unknown whether math elicitations may similarly be related to children’s math learning. Thus, here I will focus specifically on parental use of math elicitations. Eliciting and encouraging their children to engage in math-related conversations may be one way that parents create an environment that supports math, which may in turn be related to children's math learning.

1.3 Child Responsiveness

In addition to looking at the role that parents may play in shaping children's math learning, I will also examine the role of the child in this study. Past work has indicated that student engagement, which was defined as active involvement in learning activities, is positively correlated with academic achievement (Lei, Cui & Zhou, 2018). Math elicitations in particular may be an invitation to engage children in the conversation and help scaffold children's focus to mathematical stimuli. Recent work has found that parent math prompts may encourage children's own math talk (Eason et al., 2021), and other work has found that children's own math talk relates to their performance. Specifically, Pruden, Levine, and Huttenlocher (2011) found that parents' use of spatial language was positively correlated with children's production of spatial language, which subsequently predicted children's later spatial abilities. It seems that parental math talk, and math elicitations in particular, may encourage children's math talk, which in turn may lead to better math learning.

Additionally, some recent work suggests that children may benefit differently from high levels of parent math talk based on their own cognitive abilities (Silver, Elliott & Libertus, in press). Children who are more engaged may be more responsive to their parent and reply to their elicitations with math talk, and children who are more responsive to their parents' elicitations may be better able to attend to this math input. Therefore, more responsive children may benefit more from exposure to math elicitations and the opportunity to learn and use math talk that they provide, compared to children who are less responsive. Here, I intend to test whether this is indeed the case.

1.4 Project Aims

My research project has three aims: First, I will examine how parents interact naturally with their children, specifically focusing on how often parents use math elicitations and whether there are individual differences between parents in the frequency of math elicitations they use when speaking to their child. I will also examine whether there are individual differences between children in their responsiveness to their parents' math input.

The second aim of this study will be to investigate how parental use of math elicitations and children's responsiveness to their parents' math elicitations are independently related to children's math performance. I will examine whether higher parental frequency of math elicitations is associated with better math performance in their children. Further, I will test whether higher child responsiveness to their parents' math elicitations is associated with better math performance.

The final aim of this study will be to measure whether children's responsiveness, specific to the math elicitations that their parents use, is related to their math performance. Specifically, I will examine whether children's responsiveness to their parents' math elicitations may moderate the relation between parental use of math elicitations and children's math performance. It may be the case that even if a parent uses a lot of math elicitations, if their child is not paying attention or responding to that math input, then the parental input may not make a difference in the child's math learning. In order to respond relevantly to their parent's math elicitation, children must be paying attention to the input. Here, I will examine how children's responsiveness to their parents' use of math elicitations is related to whether their parents' use of math elicitations predicts their math performance. I hypothesize that children who more frequently respond in a relevant way (signaling that they are actually paying attention to their parents' scaffolding) will benefit more from their parents' usage of math elicitations and score higher in math.

2.0 Method

2.1 Participants & Procedure

The data for this project came from a study recently completed in the Kids' Thinking Lab at the University of Pittsburgh studying parental influences on children's math performance. 140 parent-child dyads consisting of preschool-aged children (*M* child age = 3.91 years, SD = 0.6 year; 50.71% male) and one of their parents participated in this study. 83% of parents had earned at least a bachelor's degree and most parents were mothers (95%). 23 additional parent-child dyads participated but were not included in analyses due to missing data.

During their visit to the lab, parents and children participated in a short naturalistic free play interaction where they were left alone in a room and asked to play with a standardized set of toys together for 10 minutes. They were instructed to play naturally and could choose to interact however they wished during the session. To avoid any bias, the parents were not informed that the purpose of this study was to examine children's math skills. These interactions were videotaped, and the entire dialogue was transcribed by trained research assistants in the lab. All transcripts were checked by a second trained research assistant in the lab. Following the free play interaction, parents and children individually completed math assessments and parents completed a short demographic questionnaire.

2.2 Measures

2.2.1 Parent Math Elicitations

The frequency coding for elicitations was based on prior work in our lab (Elliott et al., 2017; Silver, Elliott & Libertus, in press). I, with the help of trained research assistants, went through each transcription and counted the overall number of elicitations used by the parent and identified the elicitations that were related to math. In contrast to past work, rather than searching for particular keywords (which may have missed certain instances), we instead manually read through each individual transcript to pick up on every elicitation. I operationalized a parental elicitation as any command, prompt, or question intended to evoke a response from the child. Examples include utterances such as, “What game do you want to play now?” or “Give me the yellow block.” In both of these instances the child may respond verbally or non-verbally (pointing, gesturing, nodding, following the command, etc.). More specifically, I defined a parental math elicitation as any elicitation intended to evoke a **math-related** response from the child. Some examples include “Count these blocks,” “How many cars are there?” or “What is my total for all of these groceries?” In these scenarios, the parent is trying to focus the child’s attention on math by encouraging the child to think about and use mathematical concepts (i.e., counting, addition) when forming their response. By coding both the overall number of elicitations and the number of math-specific elicitations, I am able to control for parents’ general conversational engagement and elicitation frequency with their children.

2.2.2 Child Responsiveness to Parental Elicitations

Past coding measures have tended to focus only on the parental input, but I also wanted to take into account how children are responding to these elicitations. So in addition to coding the frequency of parental elicitations, I created a novel coding scheme to measure children's responsiveness to their parents' elicitations. I developed a coding manual with detailed procedures, instructions, and operational definitions for behavioral coding. This response coding was completed for every elicitation instance within each transcript. The first step was to identify whether the child was given an opportunity to respond to the elicitation. I determined this as the parent pausing for at least 1 second after stating the elicitation. The child did not have to respond within this 1 second (so even if they took up to 45 seconds to reply, it would still be counted as a response), but I wanted to ensure that they were at least given some period of time to respond instead of the parent continuing from the elicitation to the next utterance with no time in between for the child to actually respond to the elicitation.

For all elicitations that the child was given an opportunity to respond to, I then coded whether the child did in fact respond to their parent or not. These responses could be either verbal or non-verbal (gesture, nod, etc.). For each instance that the child did respond, I then coded if the response was relevant to what their parent had elicited (i.e., did the child's response pertain to the same activity and/or appropriately attempt to follow the command or answer the question). An example of a relevant response would be if the child replied, "I need the red pencil!" to the question "Which color do you want to use now?" since this is a continuation of the same conversation and activity, and is an appropriate response to the question. On the other hand, if the child instead replied, “Wow, look at this pirate ship over here!” this would not be considered relevant, since the child has shifted their attention to a new activity.

For parent math elicitations, I also coded if child responses were relevant to the math concept in the elicitation (i.e., in their response did the child use the math concept that was elicited by the parent). It is possible for children’s responses to be relevant to the activity, but not the math concept. For instance, a child may respond to the prompt “how many eggs do you see?” by saying “there’s a happy egg, sad egg, and angry egg.” This response is relevant to the activity (and would be coded as a relevant response for appropriately responding to the elicitation), but it is not relevant to the math concept being queried. Some examples of relevancy to the math concept include if the child attempted to solve 3+2 when prompted or if they pointed to the pile with more money after their parent asked them which had more. A response was coded as relevant to the math concept even if the child’s answer was not actually correct. Table 1 displays an example of a transcribed conversation from one of the participating parent-child dyads. In this example, the parent asked what six dollars subtracted from ten dollars equals, to calculate the amount of change she should receive in an imaginary shopping exchange. The child responded by grabbing two bills from the cash register and saying, “two dollars,” but the correct answer is actually four dollars. However, this response from the child was still relevant to the activity and math concept in the elicitation, as the child attempted to solve the math problem and responded appropriately with a number. Similarly, a child asked to solve 3+2 who responded with “6” was coded as responding relevantly to the math elicitation, even though their response was incorrect mathematically. If, however, the child avoided answering, ignored the command or question, or changed the subject, the response was coded as irrelevant.

Table 1. Transcription example

Parent	I gave you a ten-dollar bill, but my total was only six dollars, so how much change should you give me back?
Child	Two dollars.

I use the proportion of how often the child responded relevantly out of the total number of math elicitations their parent asked that they were given a chance to respond to, as a measure of the child's responsiveness to their parent's math elicitations. I use the proportion of how often the child responded relevantly *to the math concept* out of the total number of math elicitations their parent asked that they were given a chance to respond to, as a measure of the child's math responsiveness to their parent's math elicitations. By coding the child's responsiveness for all parental elicitations, I am able to also control for the child's responsiveness to their parent in general.

2.2.3 Child Math Performance

Children's math performance was tested with a standardized math achievement measure, the Test of Early Mathematics Ability, 3rd edition (TEMA; Ginsburg & Baroody, 2003). This assessment is widely used to measure children's math performance between the ages of 3-9 years old. The questions encompass different math concepts, including numbering skills, number-comparison facility, numeral literacy, mastery of number facts, calculation skills, and understanding of math concepts. For this study, a trained experimenter administered the TEMA to the child in a private room during their lab visit. Questions included asking children, "Can you count out loud as high as you can?" or, "Look! This side has some dots, and this side has some dots. Can you point to the side with more dots?” Raw scores on the TEMA are used as the measure of child math performance.

2.2.4 Parent Math Performance

Parents’ math performance was assessed using the Woodcock-Johnson Tests of Achievement III (Woodcock et al., 2001). Parents were administered two subtests during their lab visit in a quiet room by a trained experimenter. In the Calculation subtest, parents were given unlimited time to complete as many math problems as they could. Questions begin with simple arithmetic and increase in difficulty to calculus. In the Math Fluency subtest, parents were given three minutes to solve as many simple arithmetic questions as they could. Scores from these two subtests were used to calculate a standardized Math Composite Score, which I use as the parent math performance measure.

3.0 Results

To address the first aim, I examined descriptive statistics and looked at parents' usage of math elicitations, as well as children's responsiveness to their parents. Descriptive statistics for all variables are presented in Table 2. Parents averaged 62.58 elicitations and of these, on average, 12.52 were math elicitations. Children responded relevantly to on average 81.10% of parents' overall elicitations and 80.12% of math elicitations. However, children responded relevantly to the math concept of math elicitations on average only 57.96% of the time.

3.1 Relations between Parent Math Elicitations, Children's Responsiveness, and Children's Math Performance

To address the second aim, I examined correlations between parents' math elicitations and children's responsiveness respectively and children's math performance to determine whether there are significant relations between children's overall responsiveness to math elicitations, children's responsiveness to the math content of math elicitations, the frequency of parents' math elicitations, and children's math achievement (TEMA) score. I hypothesized that children who are more responsive, and particularly children who are more often responsive to the math content of their parents' math elicitations, will score higher on the TEMA. Further, I hypothesized that the more frequently parents use math elicitations with their children, the better their children will score on the TEMA. Bivariate correlations are displayed in Table 2. In line with my hypotheses, children who are more responsive to the math content of their parents' math elicitations tended to have significantly higher TEMA scores ($r = .30$). Contrary to hypotheses, parents' use of math elicitations was not related to children's TEMA scores.

Table 2. Descriptive statistics and bivariate correlations for all study variables, N=140

Variable	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1 Total parent elicitations	1									
2 Total parent math elicitations	.58***	1								
3 Child proportion relevant response to all elicitations	-.14	-.06	1							
4 Child proportion relevant response to math elicitations	-.01	.08	.60***	1						
5 Child proportion relevant math response to math elicitations	-.05	.06	.27**	.50***	1					
6 Child TEMA score	.00	.01	.06	.12	.30***	1				
7 Parent Woodcock Johnson Score	-.14	-.15	-.07	-.00	.09	.18*	1			
8 Parent Education	-.00	-.02	.08	.10	.13	.32***	.39***	1		
9 Child Gender	.04	.02	-.14	-.03	-.01	.03	.03	.04	1	
10 Child Age	.09	.06	.08	.04	-.10	-.01	-.13	.06	-.07	1
Mean	62.58	12.52	0.81	0.80	0.58	10.29	104.54	0.83	0.51	3.91
SD	21.68	7.60	0.10	0.17	0.24	5.58	13.27	0.38	0.50	0.06
Min	21	2	0.50	0	0	0	79	0	0	3.75
Max	123	49	0.98	1	1	27	136	1	1	4.04

*$p < .05$, **$p < .01$, ***$p < .001$

3.2 Interactions Between Parents' Math Elicitations and Children's Responsiveness Predicting Children's Math Performance

There may be other variables at play that would moderate the expected relation between parental math elicitations and children's TEMA. Specifically, it may be that children's responsiveness to their parent moderates this association. To test Aim 3, i.e., whether the child's level of responsiveness moderates the relation between parents' use of math elicitations and children's math performance, I ran a series of linear regression models. First in Model 1, I examined the unique contributions of parent math elicitations and children's responsiveness to those math elicitations while controlling for parents' overall use of elicitations, parents' math ability, parents' education, children's overall responsiveness to their parent, and children's gender and age. I decided to control for parents' math ability and education because past work has shown that these factors are related to the quality of the home learning environment and their engagement with their children (Duncan, Magnuson & Votruba-Drzal, 2014; Dearing et al., 2012; Zadeh, Farnia, & Ungerleider, 2010). I also controlled for children's gender and age because past research finds that parents may interact with their children differently based on these factors (Thippana et al., 2020; DeFlorio & Beliakoff, 2014; Durkin et al., 1986). I wanted to ensure that the measured input was not due to any outside variables. Then in Model 2, I added an interaction term between children's responsiveness to math elicitations and parental math elicitations to test whether children's responsiveness significantly moderates the association between parental math elicitations and children's math performance. I predicted that use of math elicitations may be particularly beneficial for children with higher levels of responsiveness who pay attention, focus and respond to their parents' math scaffolding, while parental math elicitations may not be as strongly related to children's math performance when children have low responsiveness to their parents. Results from these models are displayed in Table 3.

Table 3. Regression analyses predicting children's TEMA scores from parent math elicitations and children's responsiveness to math elicitations

	Model 1		Model 2	
Variable	**B (S.E.)**	**β**	**B (S.E.)**	**β**
Total parent math elicitations	.01 (.07)	.01	.01 (.08)	.01
Child proportion relevant response to math elicitation	3.58 (3.45)	.11	2.64 (4.46)	.08
Total parent math elicitations x Child proportion relevant response to math elicitation			-.15 (.45)	-.04
Total parent elicitations	.00 (.03)	.01	.00 (.03)	.01
Child proportion relevant response to all elicitations	-1.30 (5.91)	-.02	-.52 (6.38)	-.01
Parent WJ Score	.03 (.04)	.06	.03 (.04)	.06
Parent Education Bachelors or Higher	4.25** (1.34)	.29	4.28** (1.35)	.29
Child Gender is Male	.11 (.93)	.01	.10 (.93)	.01
Child Age	-1.78 (7.63)	-.02	-1.88 (7.66)	-.02
F-statistic	F(8,131) = 2.15*		F(9,130) = 1.91	
R^2	.12		.12	

**p < .05, **p < .01, ***p <.001*

Model 1 was statistically significant in predicting children's TEMA scores and explained 12% of the variance in TEMA. Critically, the effect of parents' math elicitations was not significant, nor was children's responsiveness to their parents' math elicitations. In Model 2 I examined whether the effect of parents' math elicitations on children's TEMA scores might be moderated by children's responsiveness to their parents' math elicitations. I found that this interaction was not statistically significant, and Model 2 was not statistically better than Model 1, $F(1, 130) = 0.11$, $p = .739$.

However, responsiveness in general to a math elicitation may not be enough and instead responsiveness to the specific math concept may be more important for math learning. It may be the case that relevancy to the math concept in the elicitation is the critical component of responsiveness that predicts whether children benefit from the math elicitation. To investigate this, I used children's proportion of relevant math responses to parent math elicitations that they were given a chance to respond to and ran a second series of linear regression models. First in Model 3, I examined the unique contributions of parent math elicitations and children's math responsiveness to math elicitations while controlling for parents' overall use of elicitations, parents' math ability, parents' education, children's overall responsiveness to their parent, and children's gender and age. Then in Model 4, I added in an interaction term between children's math responsiveness and parental math elicitations to test whether children's math responsiveness to math elicitations significantly moderates the association between parental math elicitations and children's math performance. Results from these models are displayed in Table 4.

Table 4. Regression analyses predicting children's TEMA scores from parent math elicitations and children's math responsiveness to math elicitations

Variable	Model 3 B (S.E.)	Model 3 β	Model 4 B (S.E.)	Model 4 β
Total parent math elicitations	-.01 (.07)	-.01	-.01 (.08)	-.02
Child proportion relevant math response to math elicitation	6.56** (1.99)	.28	6.60** (2.08)	.28
Total parent math elicitations x Child proportion relevant math response to math elicitation			.02 (.25)	.01
Total parent elicitations	.01 (.03)	.03	.01 (.03)	.03
Child proportion relevant response to all elicitations	-1.91 (4.73)	-.03	-1.93 (4.76)	-.03
Parent WJ Score	.02 (.04)	.05	.02 (.04)	.05
Parent Education Bachelors or Higher	3.92** (1.30)	.27	3.92** (1.30)	.27
Child Gender is Male	.12 (.89)	.01	.12 (.90)	.01
Child Age	1.10 (7.42)	.01	1.10 (7.45)	.01
F-statistic	F(8,131) = 3.52**		F(9,130) = 3.10**	
R^2	.18		.18	

**p < .05, **p < .01, ***p <.001*

Model 3 was statistically significant in predicting children's TEMA scores and explained 18% of the variance in TEMA. While the effect of parents' math elicitations was not significant, children's math responsiveness to their parents' math elicitations was significantly related to their TEMA scores. A 1 SD increase in children's math responsiveness was associated with a .28 SD increase in TEMA scores. In Model 4 I examined whether the effect of parents' math elicitations on children's TEMA scores might be moderated by children's math responsiveness to their parents' math elicitations. I found that this interaction was not statistically significant, and Model 4 was not statistically better than Model 3, $F(1, 130) = > 0.00$, $p = .950$.

This results pattern is the same without the addition of any covariates, and also held with a smaller set of covariates.

4.0 Discussion

In this study, I aimed to examine whether the frequency of parental math elicitations is related to children's math abilities in early childhood. I also examined how children respond to these instances of parental eliciting, and tested whether the quantity, and/or quality, of their responses can predict their math performance. I hypothesized that parents' frequency of math elicitations would be positively related to children's math performance, and that children's responsiveness would moderate the link between parents' use of math elicitations and children's math performance. Contrary to my hypotheses, parents' use of math elicitations was not significantly related to children's math performance. Additionally, children's responsiveness did not moderate this association. However, I did find that children's math responsiveness (i.e., proportion of responses to math elicitations that were relevant to the math concept in the elicitation) was significantly related to their own math performance scores.

My findings add nuance to past work, which has shown that the quantity of parental math input is positively correlated to children's math performance (Levine et al., 2010; Ramani et al., 2015; Elliot, Braham & Libertus, 2017; Casey et al., 2018). As such, I predicted that more frequent parental math elicitations would be related to better math performance in children. There are a few possible reasons why I might not have found a significant main effect of this type of parental math talk. First, I used concurrent measures, as these data were all gathered from one lab visit. Benefits received from math elicitations may occur over a longer period of time, and so the effects of parental math elicitations may not have been observable immediately on children's math performance. I had assumed that these parent-child interactions in the lab would reflect typical interactions between parents and children at home and would be a good indicator of the more general learning environment parents are providing to their child. However, the types of interactions we see in the lab may not reflect the ways that parents and children interact at home, so using their behavior during the 10-minute free play may not be a good method of capturing their true frequency of math elicitations to their child or that the types of activities that dyads engaged in during the lab visit are highly unlikely to occur during their everyday lives. It is also possible that math elicitations may not be helpful at this age, especially if parents are not using developmentally appropriate elicitations. A hypothetical example of this would be if a parent asked their 4-year-old child to, "Point to the parallelogram!" At this age, it is probable that most children may still be learning how to identify basic shapes, so it might be far-fetched and unfair for their parent to expect them to know the correct labels for a more complex shape. Additionally, it may be that preschool-aged children may not be able to receive as much benefit from parental use of math elicitations, compared to more simplistic instances of math input, like number talk. Some past work suggests that children benefit differently from math engagement depending on their age and the developmental appropriateness of the math input (Thompson, Napoli & Purpura, 2017).

One alternative explanation that I tested here was that the lack of a main effect of parent math elicitations could possibly be explained by a moderating effect of children's responsiveness. Perhaps children's level of responsiveness to parent math elicitations may influence the benefit they receive from their parents' use of these elicitations. I thought that children's math performance may not rely only on the parents' math input; but may also depend on how children respond to it. Therefore, I hypothesized that parent math elicitations may only be helpful if children are not only paying attention but also engaging in the conversation and responding appropriately. I looked at interactions between parent math elicitations and children's responsiveness (both overall and math-specific) but found no significant moderation effects. Contrary to my prediction, parent math elicitations did not have significant effects, even when considering the child's level of responsiveness as a potential moderator.

Thus, only the main effect of children's math responsiveness was significantly predictive of children's math achievement in the present study. Importantly, this relation held even when controlling for parents' overall use of elicitations, parents' math ability, parents' education, children's overall responsiveness to their parent, and children's gender and age. These findings suggest that children's own behavioral factors may play as important, if perhaps not more important, of a role as the social parental factors in math development. Since parental elicitations were not a significant predictor of children's math performance, this suggests that the quantity and quality of the math input provided may not matter as much as how the child actually responds to it. Evidence from this study suggests that responding in general to a math elicitation may not be enough, and it may be the case that children's responses must be not only relevant generally, but be relevant to the math concept specifically, in order to be associated with benefits. In this study, I found that the children who frequently replied to their parents' math elicitations with responses related to the math concept queried in the elicitation scored the highest on TEMA.

It is important to note that children's math responsiveness was not just another way of measuring their math performance. Children did not have to answer correctly in order for their response to be coded as relevant to the math concept. Instead of just checking if they got the answer correct, I was more interested in whether the child was thinking and actively engaged in the math conversation. Table 5 shows another example from one of the participating dyads interactions. In this scenario, the parent's original math elicitation prompted the child to count the cars, which is a relevant way to respond to the 'how many' prompt. However, the child accidentally counted one of the cars twice. The parent followed up by correcting the child and directing him to start over. When the child tried a second time, he was able to accurately count the number of cars. This shows the importance of thinking about the process of math learning rather than just reaching the right answer immediately.

Table 5. Transcription example

Parent	So how many did I have altogether?
Child	Mmm, one, two, three, four…
Parent	Nope, you counted green twice. Start here.

When considering all of these findings, it is important to also consider the limitations of this study. First, the parents who participated were primarily White and highly educated. Therefore, I cannot be certain that these findings are generalizable to a broader, more diverse population. Further, the ratio of mother-child dyads to father-child dyads was skewed, as the majority of participating parents were mothers (95%). In future work, it would be interesting to investigate father-child interactions and compare the results. I would predict that fathers use more overall elicitations than mothers do, based on previous work finding that fathers produce more "why" questions than mothers (Rowe, Coker, & Pan, 2004). I might also expect that children may have more opportunities to respond relevantly when talking with fathers compared to mothers since Rowe and colleagues (2004) found that in these father-child interactions, the child tended to talk more, use more vocabulary, and produce longer utterances. Additionally, here I have drawn conclusions from the results based on the assumption that children's responsiveness is producing effects on their math performance. However, it is possible the direction of causality could be reversed. For instance, it could be the case that the better the child is at math, the more responsive they are to their parents' math questions and prompts. As such, future work using experimental designs may help determine the direction of this association.

Despite these limitations, I found a significant relation between children's math responsiveness and their math performance. This finding adds nuance to previous literature and raises ideas for directions of future study. More work is needed, but evidence from this current study suggests that for children who are less responsive, it may be worth investigating ways that would help focus their attention or capture their interest, which might subsequently lead to higher responsiveness. For example, reducing distractions that are present in the room or play area could be one possible intervention to increase levels of responsiveness. Another potential intervention could be ensuring that the elicitor is giving children the opportunity to respond to these elicitations (i.e., are children given ample time to think about and formulate a response to the question or prompt). To maximize relevancy of child responses, it may be critical for the elicitation to be worded in a clear and age-appropriate manner. Future work could investigate how the complexity of these elicitations may influence the benefit that children receive. It would also be interesting to explore whether math elicitations may be differentially affecting math performance at different points in children's math development. Overall, the results from the current study reveal a lot of exciting directions for future research, which can hopefully help researchers in this field better understand how children learn math with the goal of leading to interventions that will help reduce the variability in early math ability that is observed.

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