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PARENT INTERACTIONS DURING STEM PLAY LINKED WITH PRESCHOOLER'S STEM SKILLS: DIRECT AND INDIRECT PATHWAYS

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ABSTRACT

The preschool years represent an important period for math and spatial skill development. Prior research suggests that parent interactions during STEM activities with their preschool children contribute to child skill acquisition, but the nature of this influence is understudied. Observing 75 preschool children (49% female; M_{age} = 4.82 years) engaging in a creative building challenge with a parent (93% mothers), this study examined links between two aspects of parent interaction style (STEM-related talk, directiveness) and child math and spatial skills. Comprehensive structural equation models explored direct and indirect pathways, exploring the possibility that direct links were mediated by child use of STEM-related talk and child approaches to learning (executive function skills and task orientation). Structural equation models revealed direct pathways from parent directiveness to child math skills. In addition, indirect pathways linked parent STEM talk to child math skills mediated by child STEM talk and linked parent directiveness to child math and spatial skills mediated by approaches to learning. These findings can inform the design of interventions that support parent play strategies to cultivate the STEM skill development of their young children.

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"Regard man as a mine rich in gems of inestimable value. Education can, alone, cause it to reveal its treasures, and enable mankind to benefit therefrom."

- Baha'u'llah

Chapter 1

Introduction

The manner in which parents play with and talk to their young children during play may be linked with the early development of foundational math and spatial skills that foster later STEM (science, technology, engineering, and math) learning (Claessens & Engel, 2013; Verdine et al., 2017). Prior research suggests that parent use of STEM vocabulary and support for STEM reasoning during play promotes STEM skill acquisition (Borriello & Liben, 2018; Thomas et al., 2020). In addition, theorists have speculated that children learn more when parents avoid direct instruction and instead guide their child's autonomous exploration and discovery learning during STEM play (Weisberg et al., 2016). It remains unclear whether these parenting strategies promote child STEM skills directly or whether they function more indirectly by influencing the manner in which the child models and uses STEM vocabulary and reasoning themselves, or the more general way the child approaches problem-solving tasks. This study extended research linking parent STEM play strategies with child STEM skill acquisition in two ways. First, it examined the relative contributions of two types of parenting strategies during a creative parent-child STEM building activity: parent use of STEM talk (use of STEM vocabulary and STEM reasoning) and parent directiveness (managing the activity with explicit directions and commands). Second, it evaluated direct links between parent play interactions and child math and spatial skills in the context of hypothesized indirect links, in which parent STEM talk and directiveness associations with child math and spatial skills were mediated by child STEM talk and child approaches to learning (executive function skills and task orientation). Illuminating the nature of the links between parent play interactions and child STEM skill acquisition may be important in terms of informing the design of parent-focused educational materials and outreach programming designed to enhance the STEM learning of preschool children.

The Developmental Value of Preschool STEM Learning

Accumulating research documents the value of preschool math and spatial skill development for later STEM achievement. Preschool math skills uniquely predict child math achievement through high school, controlling for family characteristics and child early reading and cognitive skills (Watts et al., 2014). By kindergarten entry, child math skills also predict later science and reading achievement through eighth grade (Claessens & Engel, 2013). Longitudinal research on early spatial skills suggests similar predictive utility. Spatial skills at 5 years of age explain a significant amount of variance in child math achievement at 7 years of age (Gilligan et al., 2017). Similarly, spatial skills measured in kindergarten predict subsequent growth in math skills through third grade (Gunderson et al., 2012; Zhang et al., 2014). Even earlier, at 3 years of age, child spatial skills emerge as an important predictor of later spatial skills at school entry (5 years of age; Verdine et al., 2017).

While there is robust evidence that the preschool years are a critical period for STEM skill development, the processes that contribute to the acquisition of these skills have not been studied comprehensively (Casey et al., 2018). Understanding the experiences that contribute to early STEM learning can guide the design of programs to boost preschool STEM skill acquisition, thereby promoting children's readiness for future learning and long-term success (Verdine et al., 2017). Children interact extensively with their parents during their early years; understanding the parent behaviors that foster STEM competencies during this developmental period may be especially important.

Parent Use of Math and Spatial Language and Support for STEM Reasoning

One factor that appears important in early STEM learning is exposure to language that identifies and labels mathematical and spatial features of the environment (Turan & Smedt, 2022). Math language involves words that reflect math concepts, including number names, references to cardinality (set size), and relative amounts (same/equal, more/less) and refers to math operations (adding or taking away; Turan & Smedt, 2022). Preschool children have better early math ability when they are exposed to more math talk during mealtimes at home, an association that holds after controlling for maternal education, child self-regulation skills, and length of interactions (Susperreguy & Davis-Kean; 2016). Similarly, the frequency with which parents count objects with their children is associated with children's understanding of cardinality (Gunderson & Levine, 2011) and knowledge of math words (Levine et al., 2010). Parent-child play represents an important context for math learning at home; for example, Ramani et al. (2015) found that preschool children had more well-developed math skills when their parents engaged more frequently in number-related play activities and discussed more advanced number concepts during play.

In the domain of spatial skills, the use of spatial cues (i.e., language that identifies or refers to shapes and sizes, relative placement, visual perspective, location, or distance between objects) has been linked with the development of preschool spatial skills. For example, Szechter and Liben (2004) found that child spatial skills were correlated with the rate at which their parents used spatial language and made non-verbal spatial references (e.g., pointing or miming) during book reading. Several lab-based training studies suggest the link is causal by demonstrating that when adults were instructed to provide verbal descriptions of spatial stimuli, preschool children showed enhanced performance on spatial detection, memory, and mapping tasks (Dessalegn & Landau, 2008; Loewenstein & Gentner, 2005; Miller et al., 2016).

Developmental theorists have also speculated that early support for STEM thinking (e.g., observation, reasoning, and inquiry skills) fuels future STEM interest and learning (McClure, 2017). Often referred to as “STEM habits of mind,” these skills include recognizing a problem, asking questions, forming predictions, identifying and gathering evidence, and drawing conclusions (Butler, 2020). By their use of observation and inquiry during play, parents may provide scaffolding that encourages preschool STEM learning (Early Childhood STEM Working Group, 2017). For example, when parents were guided by researchers to encourage their children to observe, question, predict, and evaluate during matching and sorting activities, their children displayed more complex reasoning skills during those activities than a comparison group of children whose parents engaged in the same activities without guidance from researchers (Vandermaas-Peeler et al., 2019).

The impact of parent STEM talk and STEM thinking on child STEM skill learning may be facilitated when children adopt and use similar STEM vocabulary and habits of mind (Simoncini, 2017). Prior research suggests that parent STEM talk fosters child STEM talk, demonstrating the transmission of STEM vocabulary and reasoning via modeling (e.g., Borriello & Liben, 2018; Clingan-Silverly et al., 2017; Ferrara et al., 2011; Zippert et al., 2019). For example, rates of spatial talk by parents and children were significantly correlated when they engaged in a puzzle task together (Clingan-Siverly et al., 2017). In a study suggesting a causal link, instructing parents to focus on math concepts during parent-child tablet play led to higher rates of math talk by both parents and children relative to parent-child dyads given no instructions (Zippert et al., 2019). Similarly, instructing parents to increase their spatial talk during parent-child block play led to more spatial talk by both parents and children relative to parents who played with their children without those instructions (Borriello & Liben, 2018). Polinsky and colleagues (2017) conducted a brief intervention study at a children’s museum, randomizing parents of preschool children to explore a block wall after receiving instructions to focus on block shapes, block-building goals, or no instructions. Parents who were instructed to focus on block shapes used more shape-language and spatial terms than parents in the other conditions, and levels of parent spatial talk predicted levels of child spatial talk. Interestingly, however, it was levels of the preschoolers' spatial talk during the block wall experience (and not the parents' spatial talk) that predicted pre-intervention to post-intervention improvements in child performance on a spatial assembly task (puzzle construction). These findings suggest that child uptake of STEM talk may be an important mediator of parent STEM talk influence on child STEM skill acquisition.

Indeed, several studies suggest that gains in child math and spatial vocabulary precede and support gains in math and spatial skills respectively (Harris and Peterson, 2017). For example, Purpura and Reid (2016) found that math language skills were a significant predictor of numeracy skills even when general language skills were controlled. Purpura and colleagues (2017) also found that preschool children who were randomly assigned to an 8-week dialogic reading program that included heightened levels of mathematical language showed stronger math language skills and better math knowledge than children in the control group, documenting a causal link between math language learning and math skills. In the spatial domain, Turan and colleagues (2021) found a unique association between child spatial vocabulary and child spatial skills after controlling for general vocabulary and cognitive inhibition skills. Simms and Gentner (2019) showed that knowledge of spatial vocabulary (understanding the words "middle" and "between") enabled preschool children to find an object hidden at the midpoint between two landmarks. Following children longitudinally, Pruden and colleagues (2011) found that parent spatial talk during the toddler years predicted child spatial talk at age 4.5 years which, concurrently, predicted child performance on spatial tests.

In addition to the content of the language parents use during STEM play, parent interaction style and use of directive management language may influence child STEM skill learning (Vandermaas-Peeler et al., 2019).

Parent Directiveness versus Guided Discovery Learning

A long-standing tenet of preschool education is that early learning opportunities should be child-centered, scaffolded by adult management language that offers children choices and encourages their self-initiated exploration of play materials rather than directing their behavior (National Association for the Education of Young Children, 2020). Conceptually, this kind of child-centered discovery learning fosters intrinsically motivated and self-regulated approaches to learning in ways that are not accomplished by adult-directed explicit instruction (Alfieri et al., 2011; Stipek et al., 1998). Experts similarly recommend child-centered, guided discovery learning as an optimal context for informal STEM learning during parent-child play (Vandermaas-Peeler et al., 2019; Weisberg et al., 2013). In this approach, parents let children take the lead in the play, minimizing direct instructions and scaffolding child STEM learning with the use of inquiry and comments (Vandermaas-Peeler et al., 2019; Weisberg et al., 2016).

Empirical evidence supports the general effectiveness of child-centered discovery learning as an instructional approach (Stipek et al., 1998), but evidence regarding its superiority over explicit instruction for teaching STEM skills during adult-child interactions is mixed. In support of a guided play approach, Fisher et al. (2013) found that preschool children more effectively learned the properties of four geometric shapes when adults used questions to help the child explore and compare features of various shapes they played with than when adults provided direct instruction. In contrast, Eason and Ramani (2020) found that parents and their preschool children engaged in more math talk when parents were asked to provide formal instruction than when they were asked to guide the child's play (although parents rated the guided play condition as more enjoyable).

Even when they do not directly teach STEM skills, child-centered learning opportunities may be more effective that adult-directed learning at strengthening the child's capacity for self-regulated approaches to learning and thereby indirectly contribute to STEM competencies (see Stipek et al., 1998). Several studies suggest that high levels of parent directive control may impede the development of self-regulated learning, including executive function (EF) skills (Fay-Stammbach et al., 2014) and task orientation (Wang et al., 2017). EF refers to cognitive processes that support goal-oriented learning and flexible problem-solving, including inhibitory control, attention shifting, and working memory (Blair, 2016). Task orientation reflects one's ability to regulate attention, emotions, and behavior and persist in focused efforts when faced with problem-solving challenges (Wang et al., 2017). Together, these abilities can strengthen the pace of learning by increasing attention and persistence when engaging in learning tasks and supporting collaborative problem solving and goal-oriented learning behaviors (Barkley, 2001; Blair, 2002; Greenberg, 2006).

Several studies have linked low levels of parent directiveness with positive EF development during early childhood. In one study, Bindman and colleagues (2013) videotaped parent-child dyads during a play activity and examined parent use of management language characterized as high control (directives and commands) or low control (questions, suggestions, and comments). Parents' use of high control management strategies was negatively associated with child EF whereas their reliance on questions and statements that supported child autonomy was positively associated with child EF at age 3. Conversely, low levels of parent directiveness (offering choice) during a puzzle activity was significantly correlated with child EF across four different samples (Castelo et al., 2022). Relatedly, longitudinal studies have linked parenting strategies that are less directive and low in intrusive control with growth in child EF skills during the preschool years (Hammond et al., 2012; Lengua et al., 2014).

Less research has explored links between parent directiveness and child task orientation, but the pattern of findings is parallel to research on parent directiveness and child EF. For example, Wang et al. (2017) found that children with more adaptive task orientation profiles were more likely than other children in the sample to have parents who were low in restrictive control and more accepting of their children's initiatives and behaviors. Thus, research suggests that parents who limit directive management and are instead more child-centered during playful learning activities foster the development of self-regulated approaches to learning. Approaches to learning may, in turn, fuel goal-oriented problem-solving efforts that support STEM skill acquisition.

Indeed, research documents positive associations between preschool approaches to learning (especially EF) and math skills, when controlling for general intelligence (Blair & Raver, 2014; Blair & Razza, 2007). Clements et al. (2016) examined the literature base and found evidence of correlational links between EF and math achievement. More specifically, researchers found that preschool EF was a significant predictor of early math skills (Barata, 2010; McClelland et al., 2007). In the spatial domain, Lehmann et al. (2014) found that over half of the variance in child spatial skills, specifically mental rotation, was accounted for by working memory, a key component of child EF. Researchers also found a significant correlation between the spatial skill of perspective taking and EF tasks requiring inhibitory control in young children when controlling for age, verbal IQ, and socioeconomic status (Frick & Baumeler, 2017).

Task orientation has also been linked with STEM skill acquisition. McWayne and colleagues (2004) found that teacher rated task orientation in preschool (persistence, attention, motivation, and responses to learning tasks) was significantly associated with concurrent academic skills. Longitudinally, Fitzpatrick and Pagani (2013) similarly found that kindergarten teacher ratings of child task orientation (e.g., following instructions, working autonomously) predicted child math scores three years later, controlling for skills in kindergarten.

The Present Study

This study extended research linking parent interactions during STEM play with child math and spatial skills. Prior research suggests that two types of parent play behaviors may contribute to child STEM skill acquisition during the preschool years: 1) parent use of STEM talk (math and spatial vocabulary and STEM habits of mind) and 2) parent directiveness during child-centered discovery learning. One aim of the present study was to examine these two components of parent interaction in the same model to better understand their relative associations with child skill acquisition. Second, most research in this area has only examined direct associations between parent-child interactions during STEM activities and child STEM skills. Several studies suggest the potential importance of indirect or mediated pathways rather than direct links. For example, parent STEM talk may support child STEM skill acquisition when children model and uptake STEM talk (Polinsky et al., 2017; Pruden et al., 2011). That is, links between parent STEM talk and child STEM skill acquisition may be mediated by child STEM talk. In addition, research is mixed regarding the direct links between parent directiveness during STEM activities and child STEM skill acquisition (Eason & Ramani, 2020; Fisher et al., 2013). However, multiple studies have linked lower levels of parent directiveness with growth in EF skills and task orientation (Fay-Stammbach, 2014), and several other studies have linked approaches to learning (EF and task orientation) with math and spatial skill acquisition (Barata, 2010; Blair & Raver, 2014; Blair & Razza, 2007; Clements et al., 2016; Frick & Baumeler, 2017; Lehmann et al., 2014; McClelland et al., 2007). These studies suggest that links between parent directiveness during STEM activities and child STEM skill acquisition may be mediated by child approaches to learning (EF and task orientation). Thus, this study extended previous research by evaluating direct and indirect pathways simultaneously in comprehensive models predicting child math skills and (separately) child spatial skills.

This study involved observations of parents interacting with their preschool children while completing a novel building challenge. Videotapes of these interactions were transcribed and coded for parent behaviors that reflected two dimensions: STEM talk and parent directiveness during play. These two dimensions of parent behavior were considered together in the study models to evaluate the unique associations between the content of parent talk (STEM talk) and the style of parent interaction (directiveness). Child STEM talk was also coded during the parent-child play interactions and child math and spatial skills were assessed using standard measures. Observer ratings assessed child task orientation during the assessment sessions. Two hypotheses were tested:

Hypothesis 1: It was hypothesized that parent play behaviors (STEM talk and directiveness) would show concurrent direct associations with child math skill development that were mediated by their association with child STEM talk and approaches to learning. See Figure 1-1.

Hypothesis 2: It was hypothesized that parent play behaviors (STEM talk and directiveness) would show concurrent direct associations with child spatial skill development that were mediated by their association with child STEM talk and approaches to learning. See Figure 1-2.

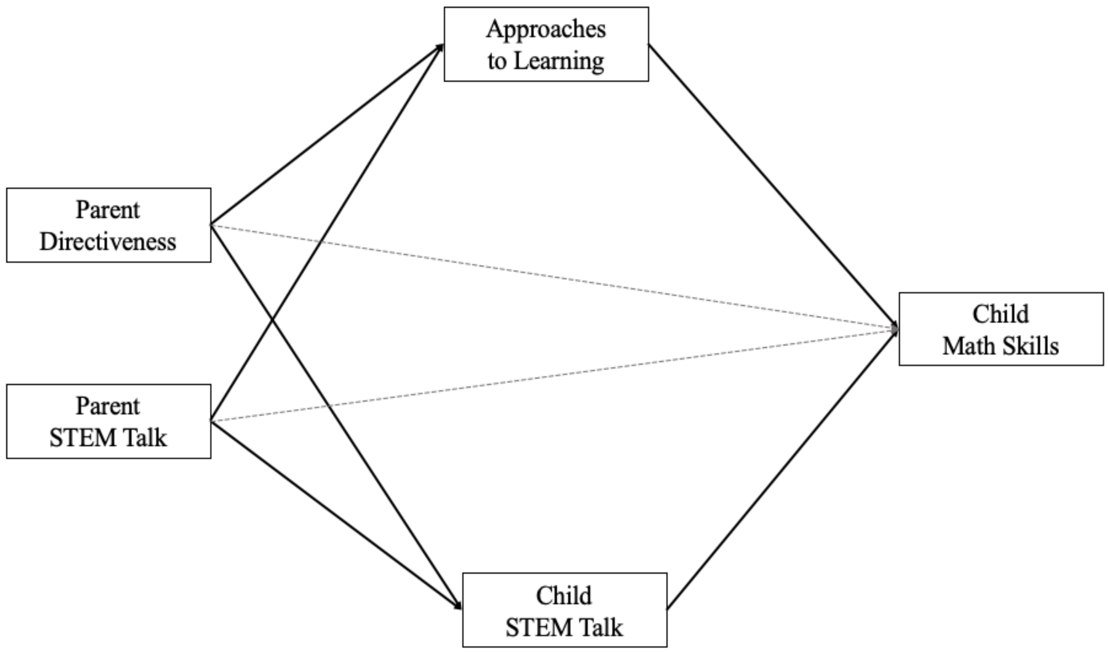

Figure **1-1**: Proposed Model - Hypothesis 1.

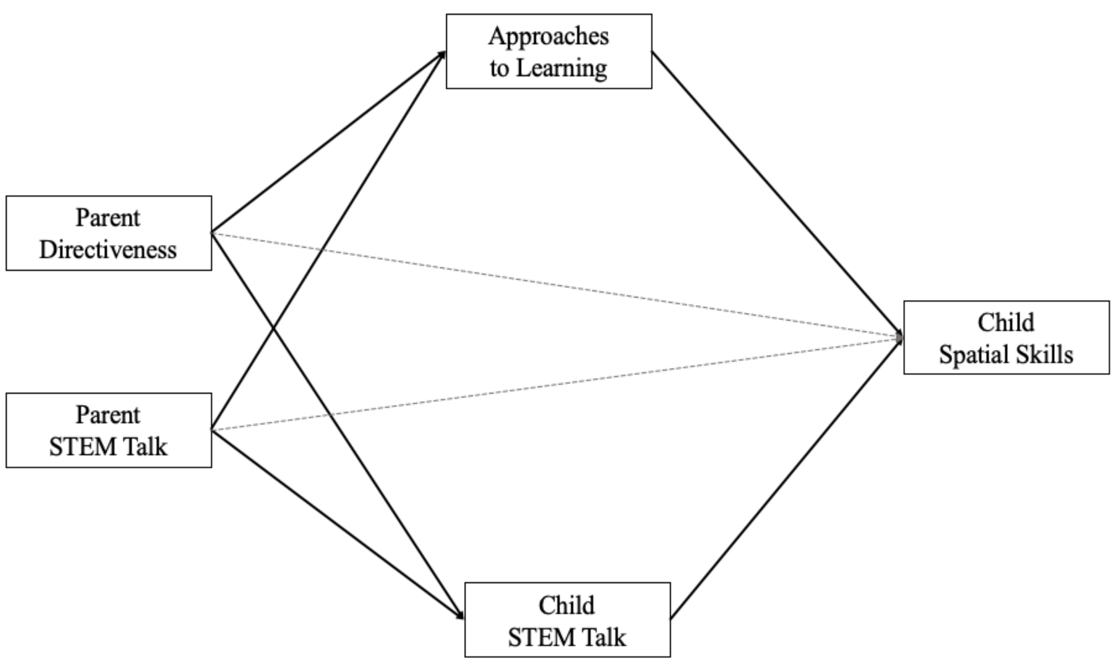

Figure **1-2**: Proposed Model - Hypothesis 2.

Chapter 2

Method

Participants

Participants were recruited from underserved rural communities and a college town in central Pennsylvania through social media advertisements and flyers mailed to families enrolled in local preschool and kindergarten programs. The sample included 75 children (49% female, 51% male; M_{age} = 4.82 years, SD = 0.49 years, range 4.01 to 5.95 years old) and their parents (93% female, 7% male). Parents reported on child gender and race (94% White, 3% Black, 1% Biracial, 1% Asian, 1% Native American). Participating primary caregivers included the child's parent (96%), grandparent (3%), or step-parent (1%). Most were married or living with a partner (96%). There was a wide range of parent education levels in the sample (27% had completed high school or earned a GED, 44% had earned a 4-year college degree, and 29% had earned a post-college graduate school degree).

Data Collection Procedures

Data for this study was collected as part of a larger project focused on designing and evaluating strategies to help parents scaffold their preschool children's STEM play in informal learning contexts. This study utilized the pre-intervention assessments, examining parent-child interaction and child skills prior to any intervention involvement. To facilitate capacity for family participation during the COVID-19 pandemic, this study utilized virtual data collection. Trained research assistants administered assessments via zoom that measured child EF, math, and spatial skills and then rated the child's task orientation during the assessment session. Research assistants explained a STEM-related building challenge to parents and children and then recorded their play interactions over zoom as they completed this task. Video recordings were subsequently transcribed and coded by a second team of research assistants for parent STEM talk, parent directiveness, and child STEM talk. No participants were missing data for any variables. All study procedures followed the American Psychological Association standards for ethical research and had the approval of the university IRB.

Measures

Parent Behaviors

Observation task. Modeled after a task used by Pattison and colleagues (2018), each parent-child dyad was given fifteen minutes to build a lookout for two mice who were escaping a cat, including providing a way for the mice to climb up to the lookout and giving them a fast way to get down. Parent-child dyads were given building straws and connectors, card stock, craft rolls, craft sticks, tape, and shape stickers. If the dyad finished in under fifteen minutes, they were prompted twice to continue building. If the dyad was still working after fifteen minutes, they were asked to finish up. The video recordings of these play interactions were transcribed and divided into utterances. Trained research assistants first coded the structural features of each utterance into mutually-exclusive categories representing management language, including directives/commands (providing explicit directions, issuing a command to do something or stop doing something), wh- questions (questions that began with who, what, where, when, why, or how), other questions (any other type of query that was not a Wh-question), and comments/statements (any statement made toward the child that was not a directive/command or question). See Appendix A. Then research assistants coded the utterances a second time, focusing on the STEM language content of each utterance. See Appendix B. Coders identified utterances that included a focus on numerical features (questions or comments about quantity or relative quantity such as more or less) and utterances that included a focus on spatial features (questions or comments about the size or shape of things, different visual perspectives, and spatial relations such as higher/lower or behind/in front). They also identified utterances that reflected STEM habits of mind, including utterances that gathered or provided information about a problem, asked or commented on aspects of the problem, proposed ideas or asked questions regarding what might be successful, noticed or evaluated a problem-solving strategy, or explained or asked why a strategy might (or might not) be working. Thus, all utterances were coded with a structural code; they could also be coded with one or more content codes, if applicable.

The two research assistants who served as coders were trained over a period of 12 weeks. They received a written copy of the coding system, which was explained and discussed. Research assistants coded a series of practice video recordings, discussing agreements and disagreements. Research assistants did not start coding video recordings independently until they reached a threshold of inter-rater reliability with each other on all coding categories (ICC ≥ .80). During the coding process, 20% of the video recordings were coded independently by both coders to allow for the calculation of inter-rater reliability (see ICCs presented below).

Parent STEM Talk. STEM talk was a composite score that included utterances containing number talk (ICC = .88), spatial talk (ICC = .92), wh- questions (ICC = .96), and STEM habits of mind (ICC = .67). There was significant intercorrelation between these variables, ranging from $r = .22$ to $r = .74$ and a mean of $r = .48$. The utterances containing any of these aspects of STEM talk were totaled and divided by the total number of utterances during the interaction to control for differences in talkativeness between dyads. This number could exceed one, because an utterance could include more than one STEM talk code. For example, “How many do you have?” was coded as both a wh- question and as a number focused utterance. This composite code reflected more frequent use of STEM habits of mind by parents than math or spatial vocabulary. On average, parents used number talk less than once per minute (*M* = .44), spatial talk almost three times per minute (*M* = 2.81), asked wh- questions more than once per minute (*M* = 1.45), and used STEM habits of mind almost eight times per minute (*M* = 7.85). Thus, the majority of parent STEM talk included STEM habits of mind (*M* = 68.26%), followed by spatial talk (*M* = 24.44%), wh- questions (*M* = 12.35%), and number talk (*M* = 3.81%).

Parent Directiveness. Following the Bindman et al. (2013) categorization of management language, utterances that focused on directing child behavior or the course of the activity (calculated as rate per minute, ICC= .79) were used to index parent directiveness. For example, "Put that over here," and "You need to put it here" were coded as directives/commands, mirroring the code labeled "Explicit Direction" by Bindman et al. (2013). Higher scores represented more parent directiveness, and lower scores represented less parent directiveness.

Potential Mediators: Preschoolers' STEM Talk and Approaches to Learning

Child STEM Talk. Preschoolers' STEM talk was calculated in the same manner as parents' STEM talk, using a composite of utterances containing child number talk (ICC = .82), spatial talk (ICC = .92), wh- questions (ICC = .91), and STEM habits of mind (ICC = .95), divided by the total number of child utterances. Similar to their parents, there was significant correlation between the components of STEM talk for preschoolers, with a range of r = .01 to r = .78 and a mean of r = .33. This composite code reflected more frequent use of STEM habits of mind by children that use of math or spatial talk. On average, children used number talk less than once per minute (*M* = .30), spatial talk about once per minute (*M* = 1.13), asked wh- questions less than once per minute (*M* = .30), and used STEM habits of mind more than four times per minute (*M* = 4.29). Thus, the majority of child STEM talk included STEM habits of mind (*M* =

63.07%), followed by spatial talk (*M* = 15.99%), wh- questions (*M* = 4.76%), and number talk (*M* = 4.31%).

Approaches to Learning. Approaches to learning was assessed as a latent construct represented by EF skills and task orientation. EF skills were assessed with three direct assessments. In Backward Word Span (Davis & Pratt, 1995), a measure of working memory, children heard a set of words and were asked to repeat those words in reverse order. After three practice items to teach the task, children were presented with two words. Subsequent lists gradually increased the number of words in the set to a total of five words. The highest number of words a child accurately repeated in reverse order represented their score, which ranged from zero to seven. Previous research established adequate test-retest reliability for preschool children over a 3-week period (ICC = .67; Müller, et al., 2012).

Fruit Stroop (Monette et al., 2011) was used to assess inhibitory control and attention set shifting. Children were presented with three training tasks. First, they saw a page showing an array of 20 yellow and red squares and were asked to identify their colors one by one. Next, they saw a page showing an array of 20 red apples and yellow bananas and were asked to identify their colors one by one. In the third task, they were presented with a page showing an array of 20 black and white apples and bananas and asked to identify the colors the fruits should have been. Finally, children were presented with the "test" page which showed an array of 20 red and yellow apples and bananas. Some fruits were correctly colored, whereas others were the wrong color. Children were asked to name the color the fruits should be, going through the array one by one as quickly as possible. The child's score captured how many correct colors they named in 45 seconds. Previous research has established strong test-retest reliability (r = .93; Archibald & Kerns, 1999).

Finally, a third task, Day-Night (Gerstadt et al., 1994) was used to assess inhibitory control. Children were presented with a series of 24 cards, one at a time, and instructed to say the opposite of what they saw on the card. For example, children were asked to say "night" when they saw a picture of a yellow sun and "day" when they saw a picture of a moon. Mistakes were corrected during three sets of practice trials, and then children were given 16 subsequent trials without correction. Their score was the number of cards correctly identified during those 16 trials. Previous research established strong internal reliability (r = .79 - .93; Chasiotis et al., 2006; Rhoades et al., 2009; von Stauffenberg & Campbell, 2007) and test-retest reliability (r = .84; Thorell & Wåhlstedt, 2006) for this task.

Scores on each of these three EF tasks were standardized and averaged to create a composite measure representing EF (intercorrelations ranged from r = .29 to r = .53, with a mean r = .41).

Task orientation, reflecting the child's ability to persist at challenging tasks and regulate behavior, emotion, and cognition, was assessed through ratings completed by the research assistant who conducted the child assessment. The child's ability to remain focused and engaged in the assessment tasks was rated on 13-items from an adapted version of the Leiter Examiner Report (Roid & Miller, 1997; Smith-Donald et al., 2007). Items were rated using a 4-point scale with specific anchors provided for each item. For example, one item stated, "Pays attention to instructions and demonstrations." Four response options were given ranging from (1) Child spends most of time off-task, inattentive to (4) Child looks closely at pictures to distinguish between them - child attends to and complies with interviewer. Each child was given a total score between 13 and 52 with higher scores representing greater task orientation (α = .92).

Preschoolers' STEM Skills

Math Skills. Children's math skills were assessed using the Applied Problems scale of the *Woodcock – Johnson III: Tests of Achievement* (Woodcock et al., 2001). This scale assessed understanding of numbers and quantity, counting objects, and adding or subtracting small numbers. Items that assessed a child's ability to read an analog clock or count money were removed. For the first 17 items, administration was discontinued after 6 consecutive failures; for the following 15 items, administration was discontinued after 2 consecutive failures. The number of items correctly answered comprised a child's score ($\alpha = .82$).

Spatial Skills. Measures of two spatial skills – mental rotation and perspective taking – were administered based on research suggesting that these skills represent critical preschool precursor skills for subsequent spatial ability (Newcombe & Frick, 2010; Yang et al., 2020). The Children's Mental Transformation Task (CMTT; Levine et al., 1999) evaluated the child's ability to complete mental transformations by asking them to identify which shape would be made if two separate pieces were combined. It included horizontal and diagonal translation as well as horizontal and diagonal rotation. Children were presented with 3 teaching trials followed by 12 scored trials. Previous research has established sufficient split-half reliability ($r = .55$; Levine et al., 2012). The second measure, How Do Things Look? (Liben & Downs, 1993) examined visual perspective taking ability by asking a child what a doll would see when looking at a panda from different angles ($\alpha = .38$). Children were presented with 2 teaching trials followed by 6 scored trials. The child's score was the total correct of those 6 trials. Scores on these two spatial measures were standardized and averaged to create a composite measure representing spatial skills ($r = .27$).

Overview of Analysis

Preliminary analyses examined descriptive statistics and correlations among the study variables. Structural equation models were conducted using AMOS 22.0 to evaluate direct and indirect associations between parent play behaviors (parent STEM talk and parent directiveness), hypothesized mediators (child STEM talk and child approaches to learning), and child STEM skills (math and spatial skills). Separate models examined associations with child math skills and child spatial skills. Child age, gender, and maternal education were included as covariates. Bootstrapping methods were used to determine the significance levels of direct and indirect effects (Arbuckle, 2013).

Chapter 3

Results

Preliminary Analyses

Descriptive statistics and correlations among study variables are shown in Table 3-1. Parent STEM talk was significantly correlated with both hypothesized mediators (child STEM talk, $r = .65$, $p < .001$; child approaches to learning, $r = .30$, $p = .01$). Parent directiveness was also significantly correlated with both hypothesized mediators (child STEM talk, $r = -.27$, $p = .02$; child approaches to learning, $r = -.42$, $p < .001$) and also with one outcome, child math skills ($r = -.48$, $p < .001$). The two hypothesized mediators, child STEM talk and child approaches to learning, were significantly inter-correlated, $r = .37$, $p = .001$, and both were significantly correlated with child math skills, $r = .45$, $p < .001$ and $r = .69$, $p < .001$, respectively. Child approaches to learning was also significantly correlated with child spatial skills, $r = .34$, $p = .003$. Child math and spatial skills were significantly intercorrelated, $r = .43$, $p < .001$.

Direct and Indirect Associations Between Parent Play Behaviors and Child Math Skills

A structural equation model tested the hypothesis that parent play behaviors (parent STEM talk and parent directiveness) would show direct links with child math skill development and concurrent indirect links mediated by their association with child STEM talk and child approaches to learning. The structural equation model provided partial support for this hypothesis.

Interestingly, the direct association between parent STEM talk and child math skills, which was positive (although non-significant) as a correlation (r = .19, p = .12), emerged as a significant negative association in this model, β = -.24, p = .01. However, a significant indirect path positively linked parent STEM talk with child math skills, mediated by child STEM talk, β = 1.34, 95% CI [.58, 2.35] and child approaches to learning, β = .75, 95% CI [.04, 1.62]. These pathways are consistent with the interpretation that parent STEM talk contributes to child math skill learning primarily when it boosts child STEM talk and child capacity for goal-oriented learning (reflected by EF and task orientation).

The model revealed that parent directiveness was significantly associated with child math skills through a direct path, β = -.19, p = .01, and additionally through an indirect path mediated by child approaches to learning, β = -.31, 95% CI [-.54, -.10]. The indirect path linking parent directiveness with child math skills via child STEM talk was not significant, β = -.09, 95% CI [-.23, .002]. See Table 3-2 and Figure 3-1.

Direct and Indirect Associations Between Parent Play Behaviors and Child Spatial Skills

A second structural equation model assessed direct and indirect associations between parent play behaviors and child spatial skills. In this model, no direct path emerged between parent STEM talk and child spatial skills, β = -.16, p = .27. However, parent STEM talk was significantly linked with child spatial skills via an indirect pathway mediated by child approaches to learning, β =.56, 95% CI [.04, 1.53]. The indirect path from parent STEM talk to child spatial skills mediated by child STEM talk was not significant, β = .13, 95% CI [-1.17, 1.38].

Similarly, the direct path linking parent directiveness to child spatial skills was not significant, $\beta = .07$, $p = .54$. However, parent directiveness was significantly associated with child spatial skills through an indirect path mediated by child approaches to learning, $\beta = -.23$, 95% CI [-.49, -.07]. The indirect path between parent directiveness and child spatial skills mediated by child STEM talk was not significant, $\beta = -.01$, 95% CI [-.13, .07]. See Table 3-3 and Figure 3-2. These pathways are consistent with the interpretation that lower levels of parent directiveness indirectly support child spatial skills by strengthening child approaches to learning.

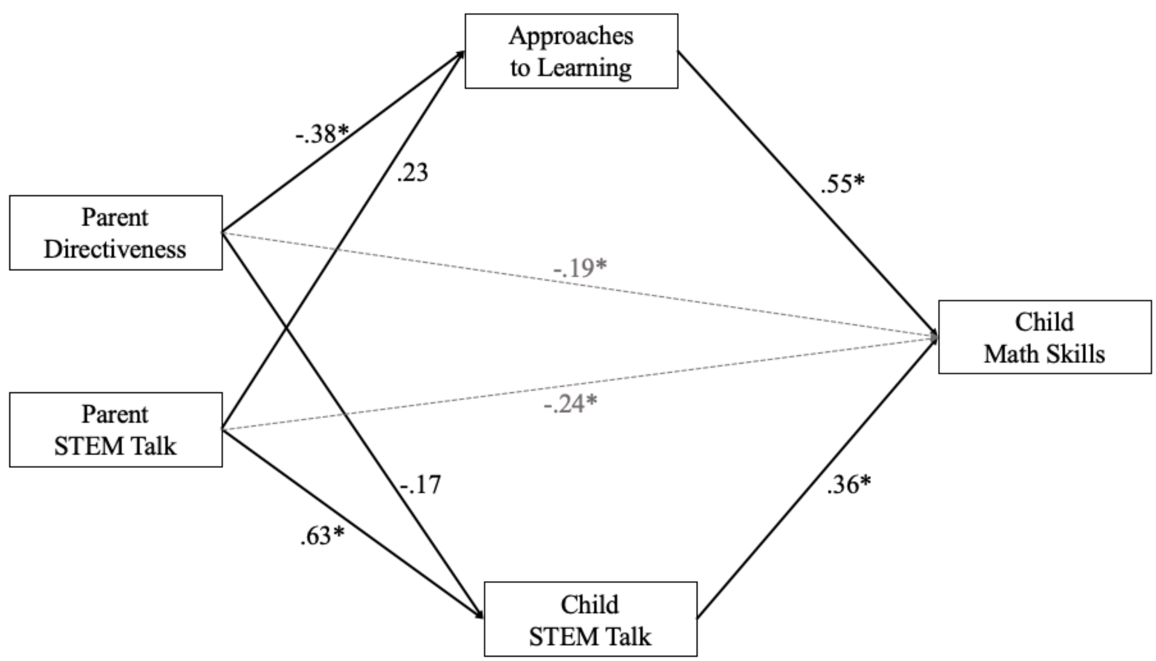

Figure **3-1**: Direct and Indirect Paths Linking Parent Play Behaviors and Child Math Skills: Individual Paths.

Note. Model covariates include child age, gender, and maternal education. Significant indirect paths linked parent STEM talk to child math skills through child STEM talk ($\beta = 1.34$, $p = .001$) and through approaches to learning ($\beta = .75$, $p = .04$) and linked parent directiveness to child math skills through approaches to learning ($\beta = -.31$, $p = .01$) * $p < .05$.

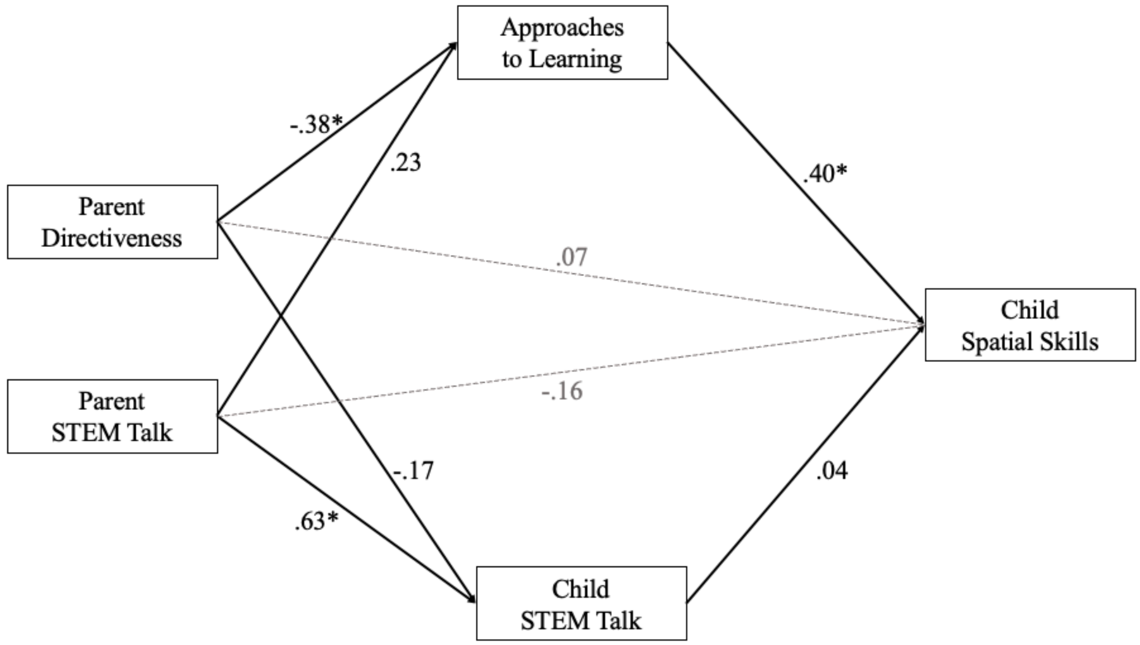

Figure **3-2**: Direct and Indirect Paths Linking Parent Play Behaviors and Child Spatial Skills.

Note. Covariates included child age, gender, and maternal education. Significant indirect paths linked parent STEM talk to child spatial skills through approaches to learning ($\beta = .56$, $p = .03$) and linked parent directiveness to child spatial skills through approaches to learning ($\beta = -.23$, $p = .01$). * $p < .05$.

Variable	*M*	*SD*	1	2	3	4	5	6	7	8	9
Parent Behaviors											
1. STEM Talk	1.09	.17									
2. Parent Directiveness	1.10	.68	-.17								
Child Mediators											
3. STEM Talk	.88	.19	.65**	-.27*							
4. Executive Functioning	.00	1.00	.24*	-.38**	.29*						
5. Task Orientation	.00	1.00	.28*	-.36**	.35**	.53**					
Child Skills											
6. Math Skills	14.08	3.34	.19	-.48**	.45**	.68**	.53**				
7. Spatial Skills	.00	1.00	-.03	-.09	.06	.34**	.25*	.43**			
Covariates											
8. Child Age	4.82	.49	-.02	-.37**	.17	.46**	.16	.43**	.20		
9. Child Gender	.49	.50	.01	.03	-.31**	.02	-.21	-.17	-.19	.01	
10. Mother's Education	.73	.45	-.05	-.31**	.07	.12	.19	.23*	.13	.11	-.07

Table **3-1**: Means, Standard Deviations, and Correlations among Study Variables.

Note. M = mean; *SD* = standard deviation. Executive Functioning and Task Orientation were standardized and combined to create a latent construct of Approaches to Learning. Two measures were standardized and combined to create a composite of Spatial Skills. Gender is coded 0 = female, 1 = male. Age is reported in years.

* $p < .05$. ** $p < .01$.

Model Effects	***β (SE)***	***95% CI***	***p***
Direct Effects of Parent Behaviors on Child Math Skills			
Parent STEM Talk	-.24 (.09)	-.43, -.05	.01
Parent Directiveness	-.19 (.07)	-.33, -.07	.01
Effects of Parent Directiveness on Mediators			
Child STEM Talk	-.17 (.10)	-.35, .03	.10
Approaches to Learning	-.38 (.14)	-.63, -.12	.01
Effects of Parent STEM Talk on Mediators			
Child STEM Talk	.63 (.06)	.49, .74	.001
Approaches to Learning	.23 (.11)	-.004, .43	.05
Effects of Mediators on Child Math Skills			
Child STEM Talk	.36 (.10)	.16, .55	.002
Approaches to Learning	.55 (.07)	.40, .67	.001
Indirect Effects of Parent Behaviors on Child Math Skills via Mediators			
Parent STEM Talk -> Child STEM Talk -> Child Math Skills	1.34 (.45)	.58, 2.35	.001
Parent STEM Talk -> Approaches to Learning -> Child Math Skills	.75 (.40)	.04, 1.62	.04
Parent Directiveness -> Child STEM Talk -> Child Math Skills	-.09 (.06)	-.23, .002	.06
Parent Directiveness -> Approaches to Learning -> Child Math Skills	-.31 (.12)	-.54, -.10	.01

Table **3-2**: Standardized Direct and Indirect Effects in the Path Model to Child Math Skills.

Note. Covariates include child age, gender, and maternal education. Direct effects estimates shown here represent the value in the full model with the indirect paths included.

Model Effects	*β (SE)*	*95% CI*	*p*
Direct Effects of Parent Behaviors on Child Spatial Skills			
Parent STEM Talk	-.16 (.14)	-.41, .12	.27
Parent Directiveness	.07 (.14)	-.18, .37	.54
Effects of Parent Directiveness on Mediators			
Child STEM Talk	-.17 (.10)	-.35, .03	.10
Approach to Learning	-.38 (.14)	-.63, -.12	.01
Effects of Parent STEM Talk on Mediators			
Child STEM Talk	.63 (.06)	.49, .74	.001
Approach to Learning	.23 (.11)	-.004, .43	.05
Effects of Mediators on Child Spatial Skills			
Child STEM Talk	.04 (.17)	-.32, .34	.90
Approach to Learning	.40 (.13)	.13, .65	.004
Indirect Effects of Parent Behaviors on Child Spatial Skills via Mediators			
Parent STEM Talk -> Child STEM Talk -> Child Spatial Skills	.13 (.64)	-1.17, 1.38	.90
Parent STEM Talk -> Approaches to Learning -> Child Spatial Skills	.56 (.36)	.04, 1.53	.03
Parent Directiveness -> Child STEM Talk -> Child Spatial Skills	-.01 (.04)	-.13, .07	.66
Parent Directiveness -> Approaches to Learning -> Child Spatial Skills	-.23 (.10)	-.49, -.07	.01

Table **3-3**: Standardized Direct and Indirect Effects in the Path Model to Child Spatial Skills.

Note. Covariates included child age, gender, and maternal education. The direct effects estimate shown here represent the value in the full model with the indirect paths included.

Chapter 4

Discussion

There is robust evidence that the preschool years are a critical period for STEM development (Claessens & Engel, 2013; Gilligan et al., 2017; Gunderson et al., 2012; Verdine et al., 2017; Watts et al., 2014; Zhang et al., 2014). Prior research also suggests that parents can promote STEM skill acquisition through their language use and interaction style during parent-child STEM play (Borriello & Liben, 2018; Thomas et al., 2020). This study extended existing research by including parent STEM talk and parent directiveness in the same model to evaluate their unique contributions to child math and spatial skills. Additionally, this study expanded research on the nature of the associations by examining both direct paths of parent influence and indirect paths of influence mediated by child use of STEM talk and child approaches to learning (EF skills and task orientation).

The hypothesis that parent play behaviors (STEM talk and parent directiveness) would be linked with child math and spatial skill development directly and indirectly, mediated by their association with child STEM talk and approaches to learning, was validated in relation to child math skills. Parent directiveness had a significant direct inverse association with child math skills as well as an indirect association mediated by child approaches to learning. Parent STEM talk had significant indirect positive associations with child math skills mediated by both approaches to learning and child STEM talk. Clearly, multiple paths account for the association between these two dimensions of parent play behaviors and child math skills.

Although the direct associations between parent play behaviors (STEM talk and parent directiveness) and child spatial skills were not significant, significant indirect associations emerged for both dimensions of parenting behaviors mediated by child approaches to learning, thereby providing partial support for the hypotheses. These findings have implications for developmental science and can inform the direction of future research examining STEM skill development during the preschool years as well as inform the design of parent-focused programming.

Math Skill Development

Prior research suggests that exposure to math concepts and language plays a fundamental role in promoting early math skills (Susperreguy & Davis-Kean; 2016; Turan & Smedt, 2022) and underscores the value of parent use of math language during play and everyday parent-child interactions as a precursor to child knowledge of math words (Levine et al., 2010; Ramani et al., 2015). Although less often studied, parent modeling of STEM thinking (e.g., observation, reasoning, and inquiry skills) is also linked conceptually with early STEM skill development (Butler, 2020; McClure, 2017; Simoncini, 2017). The results of this study confirm an association between parent STEM talk (including math language and STEM thinking) and child math skills, but clarify that this association is indirect, mediated by the child's uptake and use of STEM talk themselves and by child approaches to learning.

The mediated path linking parent STEM talk to child STEM talk to child math skills is consistent with prior studies that show similar associations (Polinsky et al., 2017). The mediational path linking parent STEM talk to child approaches to learning to math skills has not received much attention in previous research. However, the positive association between parent STEM talk and child approaches to learning is consistent with prior speculation that parents' use of observation and inquiry (e.g., STEM habits of mind) models systematic and adaptive strategies for exploring novel problems and adopting flexible approaches to problem solving (Early Childhood STEM Working Group, 2017; Vandermaas-Peeler et al., 2019). By encouraging their children to observe, question, predict, and evaluate as they tackle building challenges, parents may foster the kind of strategic attention control and set-shifting skills that are central to EF and that support persistent, goal-oriented efforts reflected in task orientation.

Interestingly, despite a simple positively-valanced correlation between parent STEM talk and child math skills (r = .19; see Table 3-1) and positive indirect links in the SEM through both child STEM talk (β = 1.34, p = .001) and approaches to learning (β = .75, p = .04), the SEM also revealed a *negative* direct pathway from parent STEM talk to child math skills (β = -.24, p = .01; see Figure 3-1). This noteworthy finding suggests that talking about STEM concepts and STEM habits of mind as a parent is not effective in fostering child math skills unless children model these behaviors and adopt STEM language themselves and there is support for developing self-regulated approaches to learning. Whereas previous researchers have found a positive direct association between parent STEM talk and child math skills (Gunderson & Levine, 2011; Levine et al., 2010; Ramani et al., 2015; Susperreguy, & Davis-Kean, 2016), these findings add an important nuance to this relationship which can help parents have effective growth producing play interactions. When developing interventions, it is likely not enough to instruct parents to increase their use of STEM talk unless they do so with a sensitive-responsive orientation in which the child can absorb and uptake these skills and behaviors.

An important feature of the present study was the examination of parent interaction style (parent directiveness) along with the STEM-related content of parent talk. Despite a strong commitment to child-centered discovery learning in early childhood (National Association for the Education of Young Children, 2020) and evidence linking parent management language (especially low levels of parent directiveness) to child learning motivation and enjoyment (Bindman et al., 2013; Stipek et al., 1998), parent directiveness is rarely studied as a factor contributing to child STEM skill acquisition. In this study, a significant direct pathway emerged between parent directiveness and child math skills, demonstrating that parents who use fewer directives and commands when engaging in STEM play have children with better math skills.

Given that the present findings are cross-sectional, it is not possible to make causal interpretations; it is possible that children with better math skills elicit less directive management language from their parents during creative building tasks. However, the association is consistent with longitudinal evidence that is suggestive of a socialization influence; for example, preschool classrooms characterized by less directive teaching promote greater gains in child learning and motivation over the course of a year (Stipek et al., 1998).

In addition, a significant indirect path emerged linking parent directiveness to lower child math skills via lower levels of child approaches to learning. Several prior studies have documented associations between parent directiveness and child development of EF skills and task orientation. This study modeled the approach taken by Bindman and colleagues (2013) who designated parent use of management language as high control (e.g., directive and commands) or low control (e.g., questions, suggestions, and comments). Other researchers have documented similar links between parent directiveness and self-regulation using broader measures of non-directive parenting such as offering choices, encouraging effort, and scaffolding problem-solving (Castelo et al., 2022l Hammond et al., 2012; Lengua et al., 2014). The mediation path that emerged in this study is consistent with these associations between parent directiveness and child EF found in prior studies (Bindman et al., 2013; Castelo et al., 2022; Fay-Stammbach et al., 2014; Hammond et al., 2012; Hughes & Ensor, 2009; Lengua et al., 2014; Obradović et al., 2016; Wang et al., 2017). The present results also extend beyond these studies to identify child approaches to learning as a key mediator of the association between parent directiveness and child math skills.

Spatial Skill Development

Two significant mediation paths emerged in this study linking both parent STEM talk and parent directiveness to child spatial skills via child approaches to learning (EF and task orientation). This indirect pathway is consistent with prior study findings regarding links between child approaches to learning and child spatial skills. Frick and Baumeler (2017) identified a positive association between inhibitory control and spatial perspective taking, whereas Lehmann and colleagues (2014) documented significant links between working memory and child mental rotation skills. In this study, the mediating variable of approaches to learning represented a composite score that included multiple EF measures (tapping inhibitory control, working memory, and attention set-shifting) and task orientation. As such, it represented a broader construct that encompassed the child's more general development of self-regulated approaches to learning including both cognitive components (EF) and motivational-behavioral components (task orientation). The study findings support a model in which parent play style (parent directiveness) and language (STEM talk) foster early spatial development by enhancing focused, flexible, goal-oriented problem-solving and learning, although bi-directional influences are also possible, with more self-regulated children eliciting less parent directiveness during cooperative building tasks.

One unexpected finding in this study was the lack of a direct path linking parent play behaviors to child spatial skills, given prior findings that established associations between parent STEM talk and child spatial skill development (Dessalegn & Landau, 2008; Loewenstein & Gentner, 2005; Miller et al., 2016; Szechter and Liben, 2004). Neither parent STEM talk nor child STEM talk were significantly correlated with child spatial skills. See Table 3-1. There are a variety of possible explanations for this. One possibility is that prior studies have used different measures to assess the spatial skills of young children than those used in this study, and some of those skills may be more highly related to parent STEM talk than others. In general, the conceptualization and measurement of spatial skills is not as straightforward in the preschool years as it is for math skills. Prior research has clearly defined a specific set of math competencies that serve as the preschool foundations for subsequent math learning progressions. For instance, researchers have found that it is important to master number recognition, counting, and cardinality before tackling more advanced math skills such as addition and subtraction (Clements & Sarama, 2020). The measure used to assess math skills in the present study (Woodcock-Johnson Applied Problems) is commonly used in studies of math learning. Conversely, there is much less clarity in how to define early spatial competency as well as how to foster spatial skills in preschool, contributing to variation across studies in spatial skill conceptualization and measurement. For example, Szechter and Liben (2004) examined spatial-graphic representation by examining child understanding of distance and relative size, whereas Dessalegn and Landau (2008) examined binding and maintenance of color-location conjugations by examining child understanding of words such as left, right, top, and bottom. While all of these skills fall within the spatial domain, a conceptual understanding of distance and relative size is distinctly different than comprehension of directional terms.

In addition, there was likely little similarity in the type of parent and child STEM talk generated in the observed building challenge activity and the type of child spatial skills measured. Consider that in the math domain, parents and children were likely counting out pieces as they built their structure and discussing whether more or fewer elements were needed. The test used to assess math skills also included counting and evaluating the relative size of sets. Conversely, given the nature of the activity, parent and child spatial talk likely focused on directional terms throughout the activity (over, under, next to, etc.) whereas the spatial skill assessment tasks focused on mental rotation and perspective taking.

There also is the possibility that the observation task used in this study failed to elicit substantive levels of parent or child spatial talk. Anecdotally, the base rates of three components that contributed to the composite STEM talk code used in the study model (utterances reflecting STEM habits of mind, spatial talk, number talk) revealed that utterances that foster STEM thinking (coded as STEM habits of mind) were most frequent and used by parents almost three times more than utterances describing spatial features of play and over eighteen times more than utterances describing mathematical features of the play. Child STEM talk followed a similar pattern; utterances that foster STEM thinking (coded as STEM habits of mind) were used by children almost four times more than talk about spatial features of play and over fourteen times more than talk about mathematical features of the play. The fact that the observation task used in this study provided parent-child pairs with ample opportunities to display STEM habits of mind but relatively fewer opportunities to use math or spatial specific vocabulary may have strengthened the study capacity to document indirect paths associated with more general STEM reasoning and problem-solving skills but less power to detect direct paths between parent STEM talk and child spatial skills.

Strengths and Limitations

This study had several strengths. Early childhood research on STEM play activities and preschool STEM skills often occurs in lab settings (e.g., Fisher et al., 2013); research exploring associations in the context of parent-child play at home remains underrepresented. This study extended previous, lab-based findings to the home environment and included parents in the play. Further, prior studies of parent contributions to STEM learning tend to focus on either parent STEM talk or parent directiveness; including both parent play behaviors in one model enhanced the capacity to understand their unique contributions and highlighted these two dimensions of parent behavior as integral components of productive parent-child play. In particular, examining links between parent directiveness and child STEM skills is important, given that it features centrally in early education research but is rarely studied in the early childhood STEM literature. The results of this study provide important evidence that parent directiveness should be considered when examining preschool STEM development and designing parent-focused programming to support preschool STEM learning.

It is also important to note the limitations of this study. Given the cross-sectional design of the study, interpretation of causality is purely speculative. It is quite possible that the developmental process involves bidirectional effects, in which parent behaviors support child approaches to learning, STEM thinking, and STEM skill acquisition and, in turn, child acquisition of these skills makes it easier for parents to be less directive in collaborative play and focus more on STEM thinking and STEM constructs. In addition, given there was only one play activity, it is unclear how much variation there would have been in parent behavior and its associations with child behavior if parent-child dyads were tasked with a range of play activities. The relatively small sample size limited the statistical power to detect significant associations and was not large enough to detect potential moderation by other parenting behaviors (such as maternal education) or child characteristics (such as language skills, educational history, prior STEM learning exposure). Lastly, the COVID-19 pandemic hampered recruitment efforts. Relying on media-based recruitment (Facebook, written flyers) likely contributed to a sample that was skewed toward parents with access to resources (computer access, capacity for zoom-based interviews). Participants were primarily White and from dual-parent households. However, 25% of the parents had a high school education or less which is only slightly lower than the national average (28%; U.S. Census Bureau, 2022). It remains unclear how well the findings will generalize to more racially and ethnically diverse populations. The need to rely on assessment strategies that could be administered virtually placed limits on the measures that could be used and may have affected child performance and parent-child interactions in unknown ways.

Directions for Future Research

In an effort to better understand parent contributions to STEM development during play, future research should compare STEM talk during various play activities to determine which types of play activities elicit specific features of STEM talk (STEM habits of mind, spatial talk, number talk). This study used an engineering task based on previous evidence that these types of tasks are engaging, enjoyable for both parents and children, and provide opportunities for STEM thinking (Pattison et al., 2018). Likely as a result, the majority of STEM talk by both parents and children was coded as STEM habits of mind. While this likely contributed to children's approaches to learning, it may not have fostered direct gains in math or spatial skills as well as play tasks that incorporate and encourage more math and spatial talk. Multiple play activities that focus on different domains of STEM learning with attention to their differential effects on types of STEM talk (e.g., habits of mind, math language, spatial language) could help researchers identify optimal play tasks for building different aspects of child STEM skills. Relatedly, an important next step is to explore features of parent STEM talk that elicit child STEM talk.

In addition, given the evidence that children who grow up in poverty enter school academically behind their more advantaged peers (Janus & Duku, 2007; Ryan et al., 2014), and the slew of benefits associated with entering school with the skills necessary for success (e.g., improved achievement, high school graduation rates, and employment outcomes; Campbell et al., 2012; Coghlan et al., 2009; Schweinhart et al., 2005), it is imperative that future research examine the generalizability of these results to more socioeconomically diverse families. It is possible that parent education levels and/or family culture and traditions could affect the way that parents and children interact during STEM play activities and could moderate the associations linking parent behaviors to child STEM skill learning.

Future research should also extend these findings by employing longitudinal, randomized controlled trial designs that can tease out causal links between parent approaches to STEM play and their preschooler's acquisition of math and spatial skills over time. To do so will require parent-focused intervention materials that can foster parent STEM talk and limit parent directiveness during STEM play in a manner that encourages children to adopt their parents' STEM vocabulary and habits of mind and promotes EF and task orientation. Existing research suggests that this will require more than providing parents with activities and brief instructions. For example, Reinhart and colleagues (2016) observed parents engaging in STEM-related activities with their children and noted a general reliance on direct instruction, suggesting that parents will need guidance to increase their use of STEM habits of mind and provide parent directiveness to create discovery learning opportunities for their young children. In another study, Vartiainin and Aksela (2019) interviewed parents of preschool children who participated in a 6-week online science club that involved home-based STEM activities. Parents indicated that the club had value for their children but identified two key challenges to sustaining their participation: 1) Lack of support to build knowledge and skills in the optimal manner to conduct the STEM activities with their young children, and 2) High burden on parents with lack of fun and personal enjoyment they during the activities. Based upon the interviews, Vartiainin and Aksela (2019) concluded that parents are unlikely to read text-heavy instructions or watch online demonstration videos that they perceive to be dull, suggesting that innovative designs are necessary to engage parents effectively in parent-child STEM play that is characterized by high levels of STEM talk and parent directiveness. Overall, there are few empirical studies of effective guided STEM play interventions designed for parents; this study highlights the potential value of this type of intervention for preschool STEM development.

Conclusions

This study extended research linking parent play interactions with child STEM skill acquisition by examining the relative contributions of two types of parenting strategies during a creative STEM building activity and by modeling both direct links between parent play interactions and child math and spatial skills and indirect links, mediated by child STEM talk and approaches to learning. Parents who utilized more STEM talk (STEM vocabulary and STEM habits of mind) during play indirectly supported math development in a path mediated by child STEM talk and approaches to learning. Similarly, parent STEM talk indirectly supported spatial skill development mediated by child approaches to learning. Parents who fostered child autonomy during play supported math skill development via a direct pathway and indirectly supported math and spatial skill development via a pathway mediated by child approaches to learning. Overall, the emergence of indirect pathways via child STEM talk and approaches to learning adds clarity to the various ways in which parent play behaviors may enhance child math and spatial skill development during the preschool years. These findings can be leveraged to design interventions that increase parent STEM talk and parent directiveness during play in a manner that encourages child STEM talk and fosters child approaches to learning, ultimately cultivating early STEM skills and improving long-term outcomes.

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Appendix A

Structural Coding Categories

Structural Coding Categories	
Category Definitions	**Examples**
Directives and Commands Issues a command to do something or to stop doing something. No verbal response from the child is requested. (Note: Directives may be stated in the form of a question in which case they should be coded as questions. See below.) Key words to be aware of when listening for directives: look, see, let's.	Clean up the blocks. Stop throwing the legos. Don't hit. Put the block next to the red one. Look at this. See, he fell over. (Note: When phrases beginning with "See" are in the form of a question, code as questi You need to put it here. (Note: "You need this block." is coded as a comment.) You gotta find the yellow one. Let's keep going. (Note: Only exception to phrases beginning with "Let's" is "Let's see." code as comment.) He did a trick and look what happened. (Note: In this case, the key word "look" is in the middle of the sentence but the utterance should still be coded as a directive.)
Questions Asks a question. Can either be a yes/no question, an open-ended question, or a tag question. Wh-questions should be tagged and double-coded.	Do you like playing this game? Did you hear the storm last night? What might happen next? This is a good book, isn't it? What did our surprise visitor show us yesterday? Would you put that over there please? Would you please help John pick up the blocks? How about we do this? (Functions like a directive, but if phrased as a question, code here) See all those trees? (Note: Phrases beginning with "See" are to be coded as directives unless in the form of a question.) I think it could go there, do you?
WH Questions Wh- questions should be coded as questions, but double coded also as this type of question.	Who, what, where, when, why, and how questions.
Comments and Statements This category broadly encompasses any statement that is not a directive or a question. Comments can be brief or extended, or can be a response to a child question. All minimal acknowledgements are coded as	Yes (please) (Child). No (thank you) (Child). Right. Good Job. Yes, you may have that. No, it's not time to play outside yet. It's a lizard.

comments: shh, aww, huh, oh, hmm?	I’m going to put the cow next to the horse. You’re doing such a nice job with your pieces! Your picture reminds me of the giant yellow balloon in the story we read this morning. Yesterday the weather was sunny and dry, but today it’s rainy and wet. That was a good book, huh? You need this block.

Appendix B

Content Coding Categories

Content Coding Categories	
Category Definitions	**Examples**
Number focused Directives, questions, or statements that focus on key aspects of numeracy. These include utterances that refer to the quantity or amount of thing (e.g, the number of things, whether something has more or less than something else, how many more are needed, etc.) Watch for utterance that include "how many" "more/less" and numbers. In addition, utterances that involve maki 1 – to -1 matching go here (e.g., "Is there a bed for every bear"?) Statements that refer to the size of things and are base visual comparison (rather than count/quantity) are cod in spatial-focused rather than here. If someone uses the term "more" or "all" to refer to something that is not in reference to a numerical comparison, as in "I need more tape" or "I have all the sticks", it does not count as number focused. Similarly, if someone refers to running out of something, "It is the last one", "That's all we have", it not number-focused because they are not assessing quantity, but just noticing they don't have something they want/need.	We need 4. Count them with me. How many do you have? I don't think you have enough. How many altogether? One pile has more.
Spatial focused Directives, questions or statements that point out or refer to spatial features of the context or play. These include utterances about the shapes and sizes of things, the relative placement of things, different visual perspectives, distances betwee things. Watch for utterances that include shape names (round, square), spatial relations (up/down, higher/lower, behind/in	The roof should be pointed. Is it a square or a rectangle? Look at it from over here. Let's put it under that. This side is higher than that one. The bears think it is a huge plate. That's too big. Put the small one on top. They need a little car. It's some bigger paper.

front of, around), and spatial comparisons (longer/sho bigger/smaller). Utterances the describe the size or dimensions of things go here ("they need a little car." some bigger paper".)	- Is the ramp steep enough for cars to go? also code in STEM habits Is that big enough? – also code in STEM habits Is the wall tall enough? – also code in STEM habits
STEM habits of mind Directives, questions, or statements that: Gather or provide information about a problem – Ask about or comment on different aspects of The problem Propose ideas or ask questions about what might work (or how things work) – Suggest an Idea for something to try or ask a question about whether something could work, suggest or ask about a plan or approach. Notice and evaluate a strategy – identifying what worked or did not work; explaining what worked or what went wrong.	What can you use to make the beds? I think we can use these parts. There are big ones and small ones here. How many do you have? How do you want to start? What should we do first? Will that be big enough? Will that keep the rain out? We should use the tape here. How can we get it to stand up? Good idea! Yes, that fits. Oh, was that too big too? I don't think that will stick. What's wrong with that one?