Linking Parents' Play Strategies with their Preschoolers' STEM Skills: The Mediating Roles of Child STEM Talk and Self-Regulated Learning

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Citation: Mannweiler, M.D., Bierman, K.L., & Liben, L.S. (2025). Linking parents' play strategies with their preschoolers' STEM skills: The mediating roles of child STEM talk and self-regulated learning, *Journal of Experimental Child Psychology, 249*, 106095.

Abstract

Previous studies document associations between parents' use of guided play strategies and children's STEM skills. We extended existing research by exploring mediating mechanisms that may account for these links. Parents played with their preschool children (N=75; 49% girls, 51% boys; 94% White, 3% Black, 1% Biracial, 1% Asian, 1% Native American; M_{age} = 4.82 years), undertaking a building challenge. Videotaped play was coded for parents' guiding STEM talk (density of math, spatial, and scientific inquiry language) and management strategy (high- vs. low-directiveness). Mediators included children's STEM talk during play and self-regulated learning (assessed by executive function tests and examiner's ratings of children's task orientation). Structural equation models confirmed hypothesized mediated paths from parent STEM talk to child math (but not spatial) skills via child STEM talk, and from parent STEM talk and directiveness to child math and spatial skills via child self-regulated learning. We discuss implications for future research and intervention design.

Keywords: parenting strategies, play, preschool, STEM skills, self-regulated learning

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Preschool math and spatial skills provide a foundation that supports and predicts later science, technology, engineering, and math (STEM) interests and competencies (Claessens & Engel, 2013; Gilligan et al., 2017; Watts et al., 2014). Research has linked parent use of STEM-related talk to children's concurrent and later STEM-related skills (Eason et al., 2021; Levine et al., 2010; Turan & Smedt, 2022). In addition, theorists have speculated that children learn more and develop better problem-solving skills when parents avoid the use of directive or highly controlling management styles with their children during STEM play and instead encourage their children to initiate exploration and discovery learning (Clements et al., 2021; Weisberg et al., 2016). The present study extended existing research by testing mediation models designed to illuminate the nature of the links between these qualities of parent play strategies and children's math and spatial skills. The specific goal was to test mediation models that considered child domain-specific and domain-general learning, both of which have been identified as areas of growth fostered by guided play approaches (Sobel, 2023) and associated with the acquisition of math and spatial skills (Verdine et al., 2014). Specific mediators examined were the child's: (1) use of STEM talk, reflecting domain-specific STEM learning, and (2) capacity for self-regulated learning (e.g., executive functions and task orientation), reflecting domain-general learning. Understanding the ways in which parents' play strategies support children's STEM-skill learning may inform and enhance efforts to design educational materials and outreach programming for parents and other adults working with preschool children in informal learning settings.

Parent STEM Talk During Play

One factor that appears important in early STEM learning is exposure to language that identifies and labels mathematical and spatial features of the environment. Math language encompasses words that reflect math concepts, including references to cardinality, comparison of relative amounts (same/equal, more/less), and discussion of math operations (adding or taking away; Turan & Smedt, 2022). Several studies suggest that preschool children show better early math ability when their parents count objects with them (Gunderson & Levine, 2011; Levine et al., 2010), engage more frequently in number-related play activities (Ramani et al., 2015), and expose them to math concepts and vocabulary (Eason et al., 2021; Susperreguy & Davis-Kean, 2016).

In the domain of spatial skills, parents' use of spatial descriptives (e.g., language that identifies or refers to shapes, relative placement, visual perspective, location, or distance between objects) has been linked with the development of preschool spatial skills (Szechter & Liben, 2004). Several studies show that when adults increase their verbal descriptions of spatial stimuli, their preschool children show corresponding improvements in acquiring the targeted spatial skills (Dessalegn & Landau, 2008; Loewenstein & Gentner, 2005; Miller et al., 2016).

Developmental theorists have also speculated that scientific inquiry language, sometimes referred to as STEM habits of mind (e.g. making observations, asking questions, testing predictions, drawing conclusions), fuels children's future STEM interest and learning (Butler, 2020; Early Childhood STEM Working Group, 2017; McClure, 2017). Supporting this hypothesis, Vandermaas-Peeler and colleagues (2019) found that children displayed more complex reasoning during matching and sorting activities when their parents were cued to scaffold their children's efforts with observations, questions, and predictions.

The kind of parent STEM talk just discussed (i.e., talk that incorporates mathematical and spatial language and scaffolds scientific inquiry) helps children notice salient features of play materials and provides them with models of how to ask questions, gather information, observe associations, and identify causal connections (e.g., Clingan-Silverly et al., 2017; Ferrara et al., 2011; Zippert et al., 2019). Rates of parent and child spatial talk during puzzle play are significantly correlated (Clingan-Siverly et al., 2017). In addition, when—as part of parent-child play—researchers encourage parents to increase their math talk (e.g., by counting, see Zippert et al., 2019) or discuss spatial qualities or actions (e.g., by commenting on shapes and their rotations, see Borriello & Liben, 2018), the rates of parent and child math or spatial talk rise together. Interestingly, when Polinsky and colleagues (2017) asked parents to focus on block shapes at a museum exhibit, it was the rate of child (and not parent) spatial talk that was associated with subsequent improvements in child performance on a spatial assembly task. Taken together, these findings suggest that child uptake of STEM talk may be an important mediator of the link between parent STEM talk and child STEM skill learning.

Children's use of STEM talk during play reflects their capacity to use math and spatial vocabulary to organize their observations, in turn facilitating math and spatial skill learning (Bower et al., 2020). Simms and Gentner (2019) showed that knowledge of spatial vocabulary (specifically, understanding the words "middle" and "between") enabled preschool children to find an object hidden at the midpoint between two landmarks. Math and spatial vocabulary predict subsequent gains in math and spatial skills (Harris & Peterson, 2017; Purpura & Reid, 2016; Turan et al., 2021). For example, Purpura and colleagues (2017) randomized preschool children to a dialogic reading intervention that facilitated gains in math vocabulary which, in turn, led to enhanced math knowledge relative to children in the control group. Following children longitudinally, Pruden and colleagues (2011) found that parent spatial talk assessed when the child was 14 to 46 months was associated with child spatial talk at age 46 months which, in turn, was associated with child performance on two of three spatial tests at age 54 months. In addition, child spatial talk during the earlier time period (14 to 46 months) mediated the impact of parent spatial talk on those spatial tests at 54 months.

A second feature of the language parents use during STEM play which may also influence child STEM skill learning is the extent to which parents use more versus less directive language to manage their children's behaviors (Vandermaas-Peeler et al., 2019; Sobel, 2023). Past research has shown that parents' use of directive management language is linked to their children's domain-general skills for self-regulated learning. As discussed next, self-regulation skills allow children to take charge of their own attention, emotion, and behavior in ways which support learning in multiple skill domains (Wilkey, 2023).

Parent Directiveness versus Guided Discovery Learning

"Guided play" frameworks encourage adults to create child-centered learning opportunities, using management language that offers children choices and encourages their self-initiated exploration of play materials rather than using language that explicitly directs children's behavior (National Association for the Education of Young Children, 2020; Weisberg et al., 2016). Conceptually, this kind of child-centered discovery learning fosters intrinsically motivated and self-regulated learning in ways that are not accomplished by adult-directed explicit instruction (Alfieri et al., 2011; Vandermaas-Peeler et al., 2019).

Empirical evidence supports the general effectiveness of child-centered discovery learning as an instructional approach (Weisberg et al., 2016), but evidence regarding its superiority over explicit instruction for teaching STEM skills during adult-child interactions is mixed (Klahr et al., 2011). 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 during play 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 child-centered discovery learning opportunities do not teach STEM skills directly, they may strengthen the child's capacity for self-regulated learning, thereby contributing indirectly to STEM competencies. Several studies suggest that high levels of directive control by parents impede the development of children's 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 (Zelazo & Carlson, 2012). Task orientation reflects one's ability to regulate attention, emotions, and behavior, and to persist at learning tasks when challenged or frustrated (Wang et al., 2017). Theorists have speculated that EF supports learning primarily by strengthening the cognitive skills that enable strategic attention allocation, and flexible problem-solving (sometimes referred to as "cold" EF), whereas task orientation reflects children's motivation for learning and their capacity to manage frustration and persist in efforts to reach a mastery goal (sometimes referred to as "hot" EF; see Smith-Donald et al., 2007; Zelazo & Carlson, 2012). The EF of young children is typically assessed by cognitive tasks that evaluate the child's working memory, inhibitory control, and attention flexibility. Task orientation is typically measured by observational codes that tap the young child's success in regulating their behavior and emotion in the face of challenging problems or learning tasks (Smith-Donald et al. 2007; Wang et al. 2017). Together, these two inter-dependent and complementary dimensions of self-regulation promote children's engagement in learning and their ability to select and use a range of flexible problem-solving strategies (Neuenschwander et al., 2012; Smith-Donald et al., 2007).

The link between parent directiveness during play and child EF is illustrated in a study conducted by Bindman and colleagues (2013). These investigators documented negative associations between parental use of high-control management language (e.g., directives and commands) during parent-child play and better EF skills of their preschool-aged children. Similarly, Castelo and colleagues (2022) found that parents who offered their children choices during puzzle play had children with higher EF scores – an association that held across four different samples. Longitudinal studies have linked parenting strategies that are high in autonomy support and low in intrusive control to greater growth in child EF skills during the preschool years (Distefano et al., 2018; Hammond et al., 2012; Lengua et al., 2014). There has been less research exploring links between parent directiveness and child task orientation, but existing findings parallel those seen in research on parent directiveness and child EF. For example, Wu and colleagues (2024) studied the moment-to-moment dynamics of parent-child interactions as their children tackled math problems. As predicted, when parents made comments in support of children's autonomy rather than using controlling or directive language, children responded with increased engagement and problem-solving efforts. In a more broadly focused longitudinal study, Wang and colleagues (2017) found that parents who initially displayed low levels of restrictive control had children who showed increasingly more adaptive task orientations over time.

The capacity for self-regulated learning (EF and task orientation), in turn, appears to facilitate children's learning of math and spatial skills during the preschool years (Bower et al., 2020; Clements et al., 2016; Hofkens et al., 2022). Illustrative of this generalization are findings by Bindman and colleagues (2015) who documented longitudinal links between levels of parent autonomy support in early childhood and subsequent academic achievement, mediated by child EF in preschool. Specific to the domain of STEM skills, research has also linked preschool EF with early math and spatial skills (Bower et al., 2020; McClelland et al., 2007; Verdine et al., 2014). Preschool EF also predicts subsequent math performance (Fung et al., 2020) with specific contributions identified for working memory (Lehmann et al., 2014) and inhibitory control (Frick & Baumeler, 2017). Children's persistence, attention, and motivation during learning tasks (as rated by teachers), has been shown to be significantly associated with children's concurrent academic learning in preschool (Hofkens et al., 2022; McWayne et al. 2004) and with children's math achievement scores in later elementary school (Fitzpatrick & Pagani, 2013).

The Present Study

The present study extended previous research on links between parent discourse during STEM play and children's math and spatial skills. We explored two mediating mechanisms that may underlie the association—children's STEM talk (math, spatial, and inquiry language) and children's self-regulated learning skills (EF and task orientation). Our models included two types of parent behaviors: (1) parent use of STEM talk and (2) parent directiveness. Prior research suggests that these two aspects of parent discourse are moderately correlated in an inverse direction (Clements et al., 2021); here we included both in the same model to illuminate their unique associations with children's acquisition of math and spatial skills.

We anticipated that both types of parent discourse would be linked with child math and spatial skills, but that their associations would operate via different child characteristics. Specifically, we hypothesized first, that the positive association between parent STEM talk and child math/spatial skills would be mediated by children's domain-specific engagement in STEM talk (math, spatial, and inquiry talk), and second, that the inverse association between parent directiveness and child math/spatial skill acquisition would be mediated by children's domain-general skill in self-regulated learning.

These hypotheses were tested by (a) observing parents and their preschool children playing together to complete a novel STEM-related building challenge, and (b) measuring children's math and spatial skills and their self-regulated learning skills. Our models emphasize the role of parental behaviors as influences on child behavior and learning, but we expect that actual parent-child developmental influences are transactional and bidirectional. Although the cross-sectional design of the present study cannot allow us to draw conclusions about the direction and interaction of effects, it can reveal relational links among key parent and child variables. The latter contribution is valuable for motivating future research that incorporates longitudinal designs or uses randomized control trials to test the impact of various interventions (e.g., examining children's later STEM engagement and success following dyadic play with different kinds of play materials and/or different versions of parent guidelines).

Method

Overview of Study Procedures

In the present study, parent play strategies (use of STEM talk and directive management language) were assessed during observations of parent-child dyads as they tackled a novel building challenge. One of the hypothesized mediators, child STEM talk, was also assessed during the parent-child building task. The other hypothesized mediator of child self-regulated learning (EF skills and task orientation) and the outcomes (child math and spatial skills) were measured using standard assessment tasks.

To allow family participation during the COVID-19 pandemic, all study procedures took place in participants' homes using remote methods (Zoom) for data collection. Trained research assistants first administered measures to assess children's skills as noted above, using procedures adapted for remote delivery. Then, parents and children were asked to open a box of building materials that had been delivered to their homes and parents were given instructions for the STEM-related building challenge. Play sessions were videotaped over Zoom and later transcribed and coded for parents' and children's STEM talk. All study procedures followed the American Psychological Association standards for ethical research, included parent informed consent, and had the approval of the university IRB.

These data were collected as part of an initial phase of a larger intervention project focused on designing and evaluating play materials to help parents scaffold their preschool children's STEM play in informal learning contexts. Because the data for the current study were collected before participants became involved in any aspect of the intervention (including assignment to intervention condition), the larger project is not discussed further here. Information about the larger project is described elsewhere (Bierman et al., 2024).

Participants

Participants were recruited from underserved rural communities and a college town in central Pennsylvania through social media advertisements and flyers mailed to families with children enrolled in local preschool and kindergarten programs. The sample included 75 children (M_{age} = 4.82 years, *SD* = 0.49 years, range 4.01 to 5.95 years) and their parents (93% female, 7%

male). Parents reported on child gender and race (49% girls, 51% boys; 94% White, 3% Black, 1% Biracial, 1% Asian, 1% Native American). Participating primary caregivers included the child's parent (96%), grandparent (3%), or stepparent (1%). Most participating caretakers (96%) were married or living with a partner. Parents' education levels varied widely within the sample: 27% had completed only high school or had earned a GED, 44% had earned a 4-year college degree, and 29% had earned a post-college graduate school degree.

Measures

Parent-Child Interactions

Dyadic STEM building challenge. The activity given to parent-child dyads was modeled after a task designed by Pattison and colleagues (2018). Prior research has shown that building challenges like the one selected are engaging for young children and their parents and provide a good foundation for child-led discovery learning, parent scaffolding, and collaborative planning and problem-solving discussions. Additionally, they offer opportunities to explore mathematical and spatial features of materials and design (Pattison et al., 2023). The activity used here thus represented an informal play experience with potential to illuminate variation across parent-child pairs in the degree to which STEM-related talk was incorporated and directive management language was used.

In brief, each parent-child dyad was given 15 minutes to build a lookout for two mice who were escaping from a cat, provide a way for the mice to climb up to the lookout, and give them a fast way to get down. Building materials included straws and connectors, card stock, craft rolls, craft sticks, tape, and shape stickers. If the dyad finished in under 15 minutes, they were prompted twice to continue building. If the dyad was still working after 15 minutes, they were asked to finish up. Details about the task are provided in the supplementary materials, Table S1.

Recordings of the parent-child play interactions were transcribed and divided into utterances. In the first coding pass, trained research assistants coded parents' management language, distinguishing (a) *directives and commands* (providing explicit directions, issuing a command to do something or stop doing something) from (b) *questions and comments*. In the second coding pass, research assistants coded each utterance for various kinds of *STEM talk*. These included utterances about numerical concepts (e.g., number words, quantity, cardinality, relative amounts such as more or less, or math operations of adding or taking away), spatial features (shape, visual perspective, spatial relations such as higher/lower or behind/in front), and scientific inquiry (making observations, asking questions, proposing ideas, testing predictions, evaluating a problem-solving strategy, drawing conclusions). A single utterance could be coded for more than one kind of STEM-related talk, thereby providing a metric reflecting the density or richness of STEM-related content in parent-child discourse. For example, the utterance "How many do you need to reach the top?" received a code for number talk (how many) and scientific inquiry (gathering information about a problem); the utterance "It might fit better if you turn it the other way," received a code for scientific inquiry (suggesting a solution to try) and spatial talk (spatial placement). Coding details are provided in supplementary Tables S2 and S3.

The two research assistants who served as coders were trained over a period of 12 weeks. Coders first received a written copy of the coding system. During a training period, research assistants each coded a set of practice video recordings separately and then discussed areas of disagreement with the second author who oversaw the coding process to refine their understanding of the coding system. Research assistants started coding video recordings for the study independently after they reached a threshold of inter-rater reliability with each other on all coding categories ($ICC \geq .80$). During the coding of the video recordings, a randomly selected

20% of the video recordings were coded independently by both coders to allow for the calculation of inter-rater reliability and the assessment of observer drift. ICC estimates and their 95% confidence intervals were calculated using SAS 9.4 and 2-way mixed-effects model; ICC values presented below.

Parent STEM Talk. STEM talk was a composite score based on the number of times a parent used language that was coded as STEM related (*viz.,* number talk [*ICC* = .88], spatial talk [*ICC* = .92], wh- questions [*ICC* = .96], and scientific inquiry [*ICC* = .67], overall α = .79), and divided by the total number of utterances. A single utterance could be coded for more than one STEM talk code. This STEM talk variable thus gives the average number of STEM codes per single utterance, a measure designed to control for differences in parent talkativeness (see Pruden et al., 2011 regarding the importance of a control of this kind).

Parent Directiveness. Following the Bindman et al. (2013) categorization of management language, utterances that directed child behavior or served as commands were used to index parent directiveness ("Put that over here," "You need to use the tape there", *ICC* = .79). Scores were calculated as rate per minute to reflect the frequency with which children were exposed to explicit directions during the task, with higher scores representing higher rates of parent directiveness.

Potential Mediators: Preschoolers' STEM Talk and Self-regulated Learning

Child STEM Talk. Preschoolers' STEM talk was calculated in the same manner as parents' STEM talk, using a composite score based on the number of times a child used language that was coded as number talk (*ICC* = .82), spatial talk (*ICC* = .92), wh- questions (*ICC* = .91), and STEM habits of mind (*ICC* = .95), overall α = .66, and divided by the number of the child's utterances.

Self-regulated Learning. Self-regulated learning was assessed as a latent construct represented by children's performance on tests of EF skills and systematic observations of the children's task orientation completed by trained research assistants. Three cognitive performance tasks were used to assess EF skills. On the *backward word span* task, which assessed working memory, children were asked to repeat lists of words in reverse order (Bierman et al., 2008; Davis & Pratt, 1966). The task began with instructions that explained and demonstrated reverse recall of a two-word list. The child was then given a practice 2-word list to recall in reverse order. Children who gave correct practice responses were told they were right and then asked to recall, in reverse, words on 2-, 3-, 4-, and 5-word test lists. Children who responded incorrectly on the first practice list were given additional practice with feedback, and then given the test lists. Scores could range from a low of 1 (for children who erred on the 2-word test item) to a high of 5 (for children who recalled the 5-word test list, in reverse, perfectly). The second EF task, Fruit Stroop (Monette et al., 2011), assessed inhibitory control and attention set shifting. After three training tasks explaining that apples were red and bananas yellow, children were shown an array of line drawings of 20 pieces of fruit, half apples and half bananas. Some were correctly colored (red apples and yellow bananas) whereas others were colored incorrectly (inverse colors). Children were given 45 seconds to name the color the fruit *should* be, proceeding row by row as fast as they could. The child's score was the number of correctly named colors so scores could range between 0 and 20. The third task, Day-Night (Gerstadt et al., 1994), assessed inhibitory control. Children were shown a series of 24 cards each containing a picture of the sun or moon. Children were instructed to say "night" when they saw a sun and "day" when they saw a moon. Following 8 practice items, children were tested on 16 additional cards and credited with one point for each picture labelled correctly so that scores could range between 0 and 16. Scores from the three EF tasks were standardized and averaged to create a composite measure representing EF.

Task orientation refers to a child's ability to persist at challenging tasks and regulate behavior, emotion, and cognition. Task orientation was measured by ratings made by the research assistant who conducted the in-home Zoom sessions. The child's ability to remain focused and engaged in the assessment tasks was rated on 13 items (e.g., "Pays attention to instructions and demonstrations") drawn from an adapted version of the Leiter social-emotional scale, Examiner Report (Roid & Miller, 1997; Smith-Donald et al., 2007). Each item provided a 4-point scale which included specific anchors for each scale point; higher scores represented greater task orientation (α = .92). Total scores were calculated and standardized within the sample for inclusion with EF scores in the latent construct included in analyses.

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 assesses understanding of numbers and quantity, counting objects, and adding or subtracting small numbers. Following standard administration procedures, during the first 17 items, administration was discontinued after 6 consecutive failures; for the next 15 items, administration was discontinued after 2 consecutive failures. Scores are the number of items answered correctly, allowing scores to range between 0 and 32 (α = .82).

Spatial Skills. Spatial skills were assessed with items drawn from the Children's Mental Transformation Task (CMTT; Levine et al., 1999), a task designed explicitly to measure spatial skills in preschool children. In this measure, children are shown two separate puzzle-like pieces and asked to select which of four shapes could be formed by imagining the two pieces moved together. Individual items differ with respect to the type of imagined movements needed to join the two pieces: All items require some imagined *translation*, that is, mentally moving pieces closer together horizontally and/or vertically. Some of the items also require imagined *rotation* in the plane (mentally turning rotated pieces in a clockwise or counterclockwise direction). During initial scale development (Levine et al., 1999) the task contained two parallel sets of 16-items; in later work as few as 10-items were used with comparable measurement success (Levine et al., 2012). Given time constraints for the current work, we included 12 test items taken from the publicly available version of the CMTT (Children's Mental Transformation Task (CMTT) — SILC (spatiallearning.org), allowing scores to range between 0 and 12 correct. Based on pilot testing for remote administration, we judged it important to begin by giving parents and children practice in how CMTT items would be presented and how children's responses would be recorded. Thus, we preceded the task proper with three sample items (also drawn from the CMTT) for which children were given feedback about the correctness of their responses. Before beginning the 12-item task itself, children were warned that they would do additional questions without feedback.

Overview of Analysis

In preliminary analyses we examined descriptive statistics and correlations among the study variables. We also explored the degree to which the separate STEM talk codes were represented in the composite STEM talk scores and their inter-correlations with other study variables. Structural equation models were conducted using AMOS 22.0 to evaluate mediation models that included parent play discourse (STEM talk and directiveness), hypothesized mediators (child STEM talk and self-regulated learning), and either child math or spatial skills (separate models examined associations with child math skills and child spatial skills). In these models, self-regulated learning was represented as a latent construct with two indicators (EF and task orientation). Child age, gender, and maternal education were included as covariates. Bootstrapping methods were used to determine the significance levels of the mediated paths (Arbuckle, 2013).

Results

Preliminary Analyses

Descriptive statistics and correlations among study variables are shown in Table 1. Correlations were generally consistent with the hypothesized model. The two parent play strategies (parent STEM talk and parent directiveness) were significantly correlated with both of the hypothesized child mediators, that is, with child STEM talk and the two indices of children's self-regulated learning (EF, task orientation). In turn, child STEM talk was significantly correlated with child math (but not spatial) skills, and the two indices of child self-regulated learning were significantly correlated with child math and child spatial skills.

We also explored descriptive statistics and correlations for the sub-types of STEM talk produced by parents and children while they worked together to solve the building challenge (i.e., number talk, spatial talk, wh-questions, and scientific inquiry; see Table S4 in supplementary materials). For both parents and children, the largest component of STEM talk was scientific inquiry (M_{parent} = .68; M_{child} = .63). The next most prevalent form of STEM talk was spatial talk (M_{parent} = .24; M_{child} = .12), then wh-questions (M_{parent} = .12; M_{child} = .05), and finally, number talk (M_{parent} = .04; M_{child} = .04). Likely reflecting its preponderance in the STEM talk composite, parent use of scientific inquiry showed a similar pattern of significant correlations with other measures of child STEM talk, self-regulated learning (EF and task orientation), and child math skills. In contrast, parent number talk showed a narrower pattern of specific correlations with child number talk, spatial talk, scientific inquiry, and child math skills; similarly, parent spatial talk was correlated with child spatial talk and scientific inquiry but not with the other child skills (see supplemental Table S4). Subsequent hypothesis-testing models focused on the composite scores which thus reflected multiple forms of parent and child STEM talk.

Mediation Models Linking Parent Play Behaviors and Child Math Skills

The first structural equation model included parent play behaviors (STEM talk and directiveness), hypothesized mediators (child STEM talk and the latent construct representing self-regulated learning), and child math skills (see Table 2 and Figure 1). This model validated the hypothesized path from parent STEM talk to child math skills mediated by child STEM talk, $\beta = 1.34$, 95% CI [.58, 2.35]. In addition, it identified a second mediated path via self-regulated learning, $\beta = .75$, 95% CI [.04, 1.62]. This model also validated the hypothesized path from parent directiveness to child math skills mediated by self-regulated learning, $\beta = -.31$, 95% CI [-.54, -.10]. With the mediators in the model, a direct association remained between parent directiveness and child math skills, $\beta = -.19$, $p = .01$, whereas the direct association between parent STEM talk and child math skills was reversed, $\beta = -.24$, $p = .01$. These pathways are consistent with the interpretation that parent STEM talk contributes to child math skill learning when it boosts child STEM talk and child capacity for self-regulated learning; parent directiveness contributes directly to child math skills as well as indirectly via its association with child self-regulated learning.

Mediated Models Linking Parent Play Behaviors and Child Spatial Skills

A second structural equation model included parent play behaviors (STEM talk and directiveness), hypothesized mediators (child STEM talk and self-regulated learning), and child spatial skills (see Table 3 and Figure 2). A significant path emerged from parent STEM talk to child spatial skills mediated by self-regulated learning, β =.52, 95% CI [.05, 1.44]; the hypothesized mediated path through child STEM talk was not significant, β = .16, 95% CI [-1.04, 1.61]. A second significant path was consistent with the hypothesized model in which the association between parent directiveness and child spatial skills was mediated by self-regulated learning, β = -.21, 95% CI [-.50, -.05]. These pathways are consistent with the interpretation that higher rates of parent STEM talk and lower rates of parent directiveness indirectly support child spatial skills by strengthening self-regulated learning.

Discussion

There is robust evidence that the preschool years are a critical period for STEM skill development (Gilligan et al., 2017; Verdine et al., 2017; Watts et al., 2014; Zhang et al., 2014). Prior research suggests that parents can promote child STEM skill acquisition through their language and interaction styles during parent-child STEM-related play (Pruden et al., 2011; Szechter & Liben, 2004) and that brief interventions directed to parents can significantly enhance parents' use of STEM-related language during dyadic play (Borriello & Liben, 2018). In addition, parent management styles that are low in directiveness and high in autonomy support have been linked with growth in child self-regulated learning which, in turn, is linked with STEM skills and academic achievement (Bindman et al. 2013, 2015; Distefano et al., 2018). The current study extended existing research by including parents' STEM talk and directiveness in the same model to explore unique associations with child math and spatial skills. Additionally, this study expanded past work by exploring mediation by child STEM talk and self-regulated learning.

Modelled data were consistent with the hypothesis that parent STEM talk would be linked with child math skills via its association with child STEM talk. In addition, both parent STEM talk and rates of parent directiveness were linked with child math and spatial skills via their associations with child self-regulated learning. These findings suggest that parents who use more STEM talk and are less directive towards their children give their children more opportunities to develop math and spatial skills. Of course, as noted earlier, future research using longitudinal research designs will be needed to test the directional nature of the links observed in our cross-sectional design. It is likely that children's characteristics and behaviors also affect parents' language and management styles across time. Although the current work cannot document all phases of the process, the findings in hand provide insights which are valuable for motivating additional research on the development of STEM skills during the preschool years and for the designing of parent-focused programming.

Parent STEM Talk

Prior research suggests that exposing children to mathematical concepts and language may help children develop early math skills (Susperreguy & Davis-Kean; 2016; Turan & Smedt, 2022) although the link is not found consistently (Daucourt et al., 2021). Similarly, parent use of spatial language during play has been linked with children's development of spatial skills (Dessalegn & Landau, 2008; Loewenstein & Gentner, 2005; Miller et al., 2016; Szechter & Liben, 2004). Although less often studied, parent modeling of scientific thinking (e.g., observation, reasoning, and inquiry skills) is also linked conceptually with early STEM skill development (Butler, 2020; McClure, 2017; Simoncini, 2017). Results of the present study add to past research by showing that the link between parent STEM talk and child math skills is mediated by domain-specific learning processes, reflected in the child's own adoption and use of

STEM talk. Additionally, the current study suggests that the association between parent STEM talk and both child math and spatial skills is mediated by the child's domain-general self-regulated learning processes.

The mediated path linking parent STEM talk to, first, child STEM talk and, second, to child math skills is consistent with prior studies that have shown similar associations (Polinsky et al., 2017). Interestingly, in the full structural model of the present study (which included both mediators), the direct pathway from parent STEM talk to child math skills was reversed, that is, more parental STEM talk was associated with *lower* child math skills ($\beta = -.24$, $p = .01$; see Figure 1). This finding may suggest that parent STEM talk is not directly effective in fostering child math skills but rather promotes math skills only indirectly by supporting the child's STEM vocabulary and scientific inquiry. Alternatively, rates of child STEM talk may function as a moderator, with associations between parent STEM talk and child math skills varying depending upon child use of STEM language and inquiry skills. Although more longitudinal and process-oriented research is needed, the current findings suggest that simply encouraging parents to increase their STEM talk would not be sufficient on its own. In addition, parents should be encouraged to help their children become proactive in noticing and exploring STEM phenomena.

There has been little previous empirical work examining the mediational path linking parent STEM talk to children's self-regulated learning and to children's math or spatial skills. The positive association we found between parents' STEM talk and children's self-regulated learning is consistent with prior speculation that parents' attentiveness to materials and phenomena, and parents' modeling of ways to pose and answer questions, may give children ideas about how to devise and implement systematic strategies in support of flexible problem solving. By enacting such strategies, children can enhance their control of attentional and set-shifting skills which are central components of self-regulated approaches to learning (Early Childhood STEM Working Group, 2017; Vandermaas-Peeler et al., 2019).

Parent Directiveness

An important feature of the present study was the examination of parent management styles as being more- versus less-directive during dyadic play. Despite early childhood educators' strong commitment to child-centered discovery learning (National Association for the Education of Young Children, 2020) and despite some evidence linking parent directiveness with child self-regulated learning (Bindman et al., 2013), the construct of parent directiveness is rarely studied as a factor contributing to child STEM skill acquisition. Several prior studies have documented associations between (a) parent directiveness or its inverse, autonomy support, and (b) children's levels of EF skills and task orientation (Bindman et al., 2015; Distefano et al., 2018). In addition, prior investigators have simultaneously examined aspects of parent STEM talk and autonomy support together. Clements and colleagues (2021), for example, reported moderate intercorrelations between the two during parent-child play. Wu et al. (2024) showed complementary effects on child engagement when children tackle math problems with their parents' help. Our study followed the approach taken by Bindman and colleagues (2013) who categorized parent use of management language as high control (e.g., directives 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., 2022; Hammond et al., 2012; Lengua et al., 2014). The results of the current study highlight the value of including parent directiveness and child self-regulated learning in conceptual models and empirical studies of early STEM skill development.

Significant mediation paths emerged in our work in both models, linking parent directiveness to child math and spatial skills via their negative association with self-regulated learning. Several prior studies have documented significant associations between self-regulated learning and child math and spatial skills (Bower et al., 2020; Frick & Baumeler, 2017; Lehmann et al., 2014; Verdine et al., 2014). In the current study, the mediating variable of self-regulated learning was represented by a latent score that was derived from two measures assessing EF (a composite score reflecting three tasks, one each to tap inhibitory control, working memory, and attention set-shifting) and task orientation (examiner ratings). As such, our work represented self-regulated learning processes as a broad construct which encompassed both cognitive components (EF) and motivational-behavioral components (task orientation).

Many hypotheses may be generated for these observed links. For example, perhaps parents whose children have more highly self-regulated learning strategies have less need to focus on managing their children's behavior, thereby leaving them more opportunity to be creative and joyful in supporting child-directed discovery learning and in generating and implementing dyadic STEM-related observations, games, or practices. Furthermore, associations among parent directiveness, child self-regulated learning, and child STEM skills may be transactional over time. For example, parental use of STEM talk and low rates of directive management during STEM-related play may support children's capacities to self-regulate their own learning, thereby advancing their acquisition of STEM skills and increasing their capacity to lead subsequent collaborative play with their parent. The latter can then further reduce the need for parents to be directive and may increase the child's and parent's opportunities to participate in and promote STEM discovery and reasoning. Longitudinal designs are needed to test the viability of this and other potential hypotheses, but we note that the association we found is consistent with recommendations emphasizing child-directed discovery learning as the optimal approach for fostering motivated learning in young children (Alfieri et al., 2011; Vandermaas-Peeler et al., 2019).

Study Limitations

The current study has several limitations that warrant consideration. As noted earlier, the cross-sectional design of the study means that interpretations of causal associations are necessarily speculative. It is likely that the developmental processes examined here are bidirectional or transactional, with qualities of both children's and parents' behaviors dynamically affecting one another over time.

The use of a single play task in this study creates some inherent limitations. It is unclear how much variation there would have been in parent behavior and its links to child behavior if parent-child dyads had been observed engaging in a far wider variety of activities. As noted earlier, the building challenge used in this study elicited high levels of scientific inquiry and relatively low levels of child and parent number and spatial talk, suggesting that the study findings might especially reflect the value of scientific inquiry in parent-child play. To explore this possibility, we ran the mediation model using the parent and child scientific inquiry scores (rather than their STEM talk composite scores) and found results very similar to those that emerged using the composite scores. (See Table S5 in supplementary materials.) The low incidence of number talk and spatial talk precluded our capacity to test their role separately in the mediation models. The findings thus validate the mediation model for parent and child scientific inquiry use but are unable to address the extent to which the same paths would hold for number talk or spatial talk taken separately.

Based on prior research, we had expected to find significant correlations between parent STEM talk and child spatial skills mediated by levels of child spatial talk, but our data were not consistent with this expectation. It is possible that associations were attenuated by the particular STEM challenge given to the dyad or by the particular measure used to assess children's spatial skills. Both STEM tasks and spatial assessments are highly varied (National Research Council, 2006) and methodological selections for assessing both parent-child play and particular spatial and mathematical skills may well affect the patterns of findings. The creative building task used in this study elicited relatively low rates of spatial talk and most of that talk focused on how to set up and refine the dyads' constructions. Thus, the observed kinds of parent and child STEM talk are not closely connected to the mental rotation skills measured by the CMTT test used in the current study, likely accounting for the limited observed associations. Had we instead asked parents and children to create a construction in which individual pieces must be placed and oriented in particular directions (as in assembling a jigsaw puzzle or a gear system), the dyads might have talked more about spatial translations and rotations. Such talk, in turn, might have been more strongly linked to children's performance on the particular spatial assessment task used (i.e., the CMTT) and thus might have provided a more effective test of the mediation path involving child spatial talk.

An additional limitation comes from the relatively small sample size. There is no established method for calculating statistical power for the kind of multiple mediation models used here (Hayes, 2018), but this study was likely somewhat underpowered to detect significant mediation effects (Fritz & Mackinnon, 2007), increasing risk for Type 2 error. Statistical power was also insufficient to detect potential moderating effects, such as those that might be associated with qualities of parents (e.g., levels of maternal education or individual differences in parents' math, spatial, and science skills and interests) or children (e.g., language skills, educational history, prior involvement in STEM activities).

Finally, COVID-19 hampered participant recruitment because the pandemic precluded use of our established school-based partnerships and other traditional community networks to recruit participants, and we had to rely on assessment tools that could be administered virtually. The final participant sample was primarily White, and it is unknown how well the findings might generalize to populations that are more diverse in terms of racial and ethnic diversity.

Directions for Future Research

We selected a building (engineering) activity for our study based on previous evidence that these types of activities are engaging, enjoyable for both parents and children, and provide opportunities for STEM problem solving and discussion (Pattison et al., 2018). As noted earlier, it would be important for future researchers to investigate parent and child STEM talk during a greater range of play activities to determine what types of play elicit what kinds of STEM talk (math, spatial, and inquiry talk), and to include a more varied battery of STEM skill measures. Additional research using multiple play activities and measures might address important questions about the ways in which different types of parent STEM talk are associated with child STEM skill development as well as refine more nuanced coding systems to identify key qualitative features of effective parental scaffolding of child STEM skill learning. For example, although parent use of math language has emerged as a correlate of child math skills in multiple studies (Eason et al., 2021; Susperreguy & Davis-Kean, 2016), a meta-analysis found non-significant associations between parent number talk and child math skills (Daucourt et al., 2021) suggesting that the association is nuanced and may require more complex and qualitative coding than the system used in the present study.

Future research should also extend the current work by employing longitudinal designs. Randomized controlled trials comparing the effects of promoting different parent approaches to facilitating STEM play would also be important to test hypothesized causal links between parents' approaches and preschoolers' acquisition of math and spatial skills.

Our findings also suggest that it will be important to design and evaluate the impact of parent-focused interventions that both foster parent STEM talk and limit parent directiveness during STEM play. Prior research suggests that parents tend to rely heavily on direct instruction during STEM-related activities with their children (Reinhart et al., 2016), suggesting that parents will need guidance to optimize child-directed learning opportunities. In short, existing research suggests that effective programs will require more than providing parents with lists of STEM-related words and scientific phenomena to be taught. It will be important to develop materials that pique both parents' and children's interests and questions, and that scaffold the STEM skills needed to address and answer them.

Acknowledgements

Research reported in this publication is based upon work supported by the Advancing Informal STEM Learning division of the National Science Foundation under Grant No. 1811472. Any opinions, findings, and conclusions or recommendations expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation. We greatly appreciate the efforts of the research staff and the families who participated in this study, and the community support provided through our partnerships with the Tyrone Area School District and the Discovery Space of Central Pennsylvania Science Museum. We also gratefully acknowledge the statistical consultation provided by Brenda Heinrichs, and the valuable input provided by other members of the study investigative team (Jennifer Connell, Meg Small, Jessica Menold, and Scarlett Miller) and the external advisory board (Sue Allen, Maureen Callanan, Michelle Crowl, Laura Jana, and Deborah Weber).

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Table 1.

Means, Standard Deviations, and Correlations among Study Measures

Variable	***M***	***SD***	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Parent Behaviors											
1. STEM Talk	1.09	.17									
2. Directiveness	1.10	.68	-.17								
Child Mediators											
3. STEM Talk	.88	.19	.65**	-.27*							
4. EF	.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	7.31	1.99	-.00	-.07	.08	.38**	.19	.48**			
Covariates											
8. Child Age	4.82	.49	-.02	-.37**	.17	.46**	.16	.43**	.26*		
9. Child Gender	.49	.50	.01	.03	-.31**	.02	-.21	-.17	-.09	.01	
10. Parent Education	.73	.45	-.05	-.31**	.07	.12	.19	.23*	.13	.11	-.07

Note. M = mean; *SD* = standard deviation. The STEM Talk measures for both parents and children represent the number of STEM talk codes divided by the total number of utterances; thus, the variable represents the average number of STEM codes per single utterance. Directiveness represents the average number of directives/commands per minute. Both STEM talk and directiveness were assessed during the building challenge task. EF = Executive Functioning. EF and Task Orientation were standardized and modeled as a latent construct representing self-regulated learning. Math and spatial skills represent the total correct on, respectively, the administered versions of Applied Problems and CMTT (see text). Gender is coded 0 = female, 1 = male. Age is reported in years. Parent education is a dichotomous variable, with 0 = high school/GED and 1 = 4-year college degree or more.
* $p < .05$. ** $p < .01$.

Table 2.

Standardized Direct and Indirect Effects in the Path Model to Child Math Skills

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
Self-regulated Learning	-.38 (.14)	-.63, -.12	.01
Effects of Parent STEM Talk on Mediators			
Child STEM Talk	.63 (.06)	.49, .74	.001
Self-regulated Learning	.23 (.11)	-.004, .43	.05
Effects of Mediators on Child Math Skills			
Child STEM Talk	.36 (.10)	.16, .55	.002
Self-regulated 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 → Self-regulated → Child Math Skills	.75 (.40)	.04, 1.62	.04
Parent Directiveness → Child STEM Talk → Child Math Skills	-.09 (.06)	-.23, .002	.06
Parent Directiveness → Self-regulated Learning → Child Math Skills	-.31 (.12)	-.54, -.10	.01

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.

Table 3.

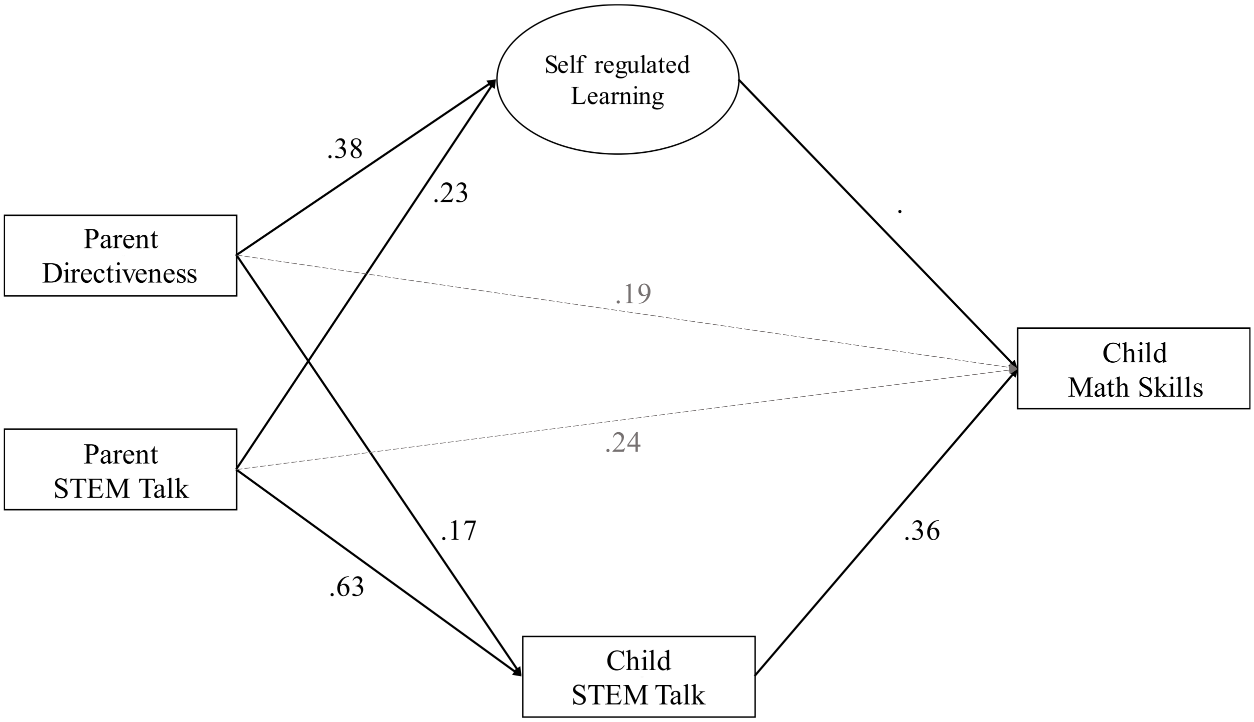
Standardized Direct and Indirect Effects in the Path Model to Child Spatial Skills

Model Effects	***β (SE)***	***95% CI***	***p***
Direct Effects of Parent Behaviors on Child Spatial Skills			
Parent STEM Talk	-.13 (.15)	-.42, .25	.38
Parent Directiveness	.08 (.12)	-.14, .33	.46
Effects of Parent Directiveness on Mediators			
Child STEM Talk	-.17 (.10)	-.35, .03	.10
Self-regulated Learning	-.38 (.14)	-.63, -.12	.01
Effects of Parent STEM Talk on Mediators			
Child STEM Talk	.63 (.06)	.49, .74	.001
Self-regulated Learning	.23 (.11)	-.004, .43	.05
Effects of Mediators on Child Spatial Skills			
Child STEM Talk	.04 (.18)	-.31, .39	.83
Self-regulated Learning	.38 (.13)	.11, .63	.01
Indirect Effects of Parent Behaviors on Child Spatial Skills via Mediators			
Parent STEM Talk → Child STEM Talk → Child Spatial Skills	.16 (.69)	-1.04, 1.61	.82
Parent STEM Talk → Self-regulated Learning → Child Spatial Skills	.52 (.34)	.05, 1.44	.03
Parent Directiveness → Child STEM Talk → Child Spatial Skills	-.01 (.05)	-.15, .07	.62
Parent Directiveness → Self-regulated Learning → Child Spatial Skills	-.21 (.11)	-.50, -.05	.01

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.

Figure 1.

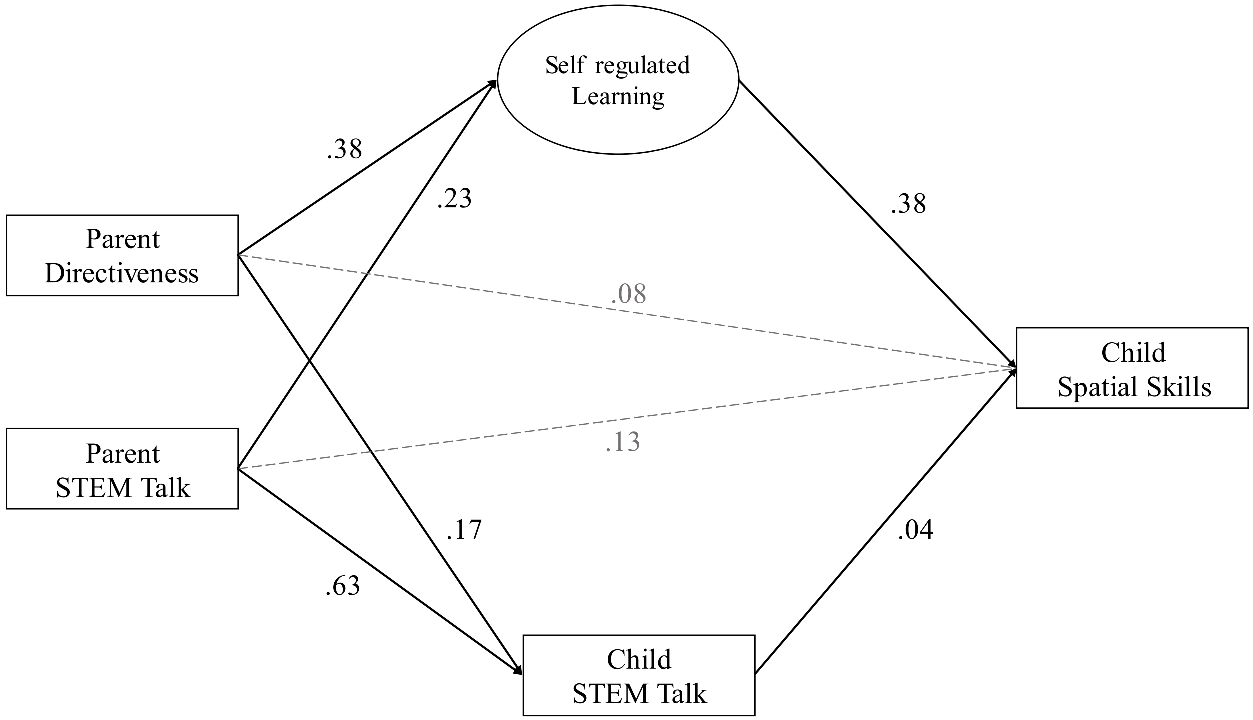
Direct and Indirect Paths Linking Parent Play Behaviors and Child Math Skills: Individual Paths



Note. Model covariates include child age, gender, and maternal education. Self-regulated learning is a latent construct indexed by EF and Task Orientation. Solid lines indicate mediated links; dotted lines indicate direct links. Significant indirect paths linked parent STEM talk to child math skills through child STEM talk (β = 1.34, p = .001) and through child self-regulated learning (β = .75, p = .04) and linked parent directiveness to child math skills through self-regulated learning (β = -.31, p = .01). See Table 2 for details.

Figure 2.

Direct and Indirect Paths Linking Parent Play Behaviors and Child Spatial Skills



Note. Covariates included child age, gender, and maternal education. Self-regulated learning is a latent construct indexed by EF and Task Orientation. Solid lines indicate mediated links; dotted lines indicate direct links. Significant indirect paths linked parent STEM talk to child spatial skills through child self-regulated learning ($\beta = .52$, $p = .03$) and linked parent directiveness to child spatial skills through self-regulated learning ($\beta = -.21$, $p = .01$). See Table 3 for details.