12-9-2021

Understanding the Home Spatial Environment

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UNDERSTANDING THE HOME SPATIAL ENVIRONMENT

A dissertation submitted in partial fulfillment of

the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

PSYCHOLOGY

by

Nelcida L. Garcia

2022

To: Dean Michael R. Heithaus
College of Arts, Sciences and Education

This dissertation, written by Nelcida L. Garcia, and entitled Understanding the Home Spatial Environment, having been approved in respect to style and intellectual content, is referred to you for judgment.

We have read this dissertation and recommend that it be approved.

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Date of Defense: December 9, 2021

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Florida International University, 2022

DEDICATION

I dedicate my dissertation to my parents (Francia Maria Garcia and Jose Nicolas Garcia) and husband (Gabi Manuel Sanchez) who have made so many sacrifices to help me fulfill my dream. This accomplishment would not have been possible without their unyielding love and support.

ACKNOWLEDGMENTS

This dissertation would not have been possible without the guidance and support of several people. First, I would like to thank my advisor Dr. Shannon Pruden for supporting me throughout all of the ups and downs of graduate school and encouraging me to take chances. I would also like to thank my committee members, Drs. Anthony Dick, Timothy Hayes, and Jacqueline Lynch for providing fresh perspective and feedback and tons of statistical consultation.

I would like to thank my parents Francia Maria Garcia and Jose Nicolas Garcia, my husband Gabi Manuel Sanchez, my siblings Christian, Sarah, and Samuel Garcia, my extended family, and my friends who are like family, Yesica Genao and Jose Moreno, for being my biggest cheerleaders throughout this process. I am also fortunate to have met many bright and kind friends during graduate school, Alexa Barton, Carlos Desme, and LaTreese Hall, whom have been excellent collaborators. Finally, this dissertation would not have been possible without Hannah Bowley and Melanie Rengel-Isea who were a tremendous help.

This dissertation was supported by the Eunice Kennedy Shriver National Institute of Child Health & Human Development of the National Institutes of Health under Award Number F31HD105422, the Society for Research in Child Development Dissertation Funding Award, and Florida International University's Psychology Development's Graduate Student Seed Fund Award.

ABSTRACT OF THE DISSERTATION

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Spatial thinking encompasses several related skills including understanding size, shape, translation and rotation of objects, and distance between objects. Individual differences in spatial thinking are important predictors of children's math and science achievement, as well as later entry into Science, Technology, Engineering, and Mathematics (STEM) disciplines. This dissertation proposes Relational Developmental Systems Theory as a lens to study spatial development. Informed by Relational Developmental Systems Theory, two empirical studies examined whether mothers' characteristics affected their parenting practices, and in turn, their children's spatial abilities (i.e., mental rotation, spatial scaling). First, in a sample of 165 mother-child dyads, mothers' spatial ability was examined in relation to the home spatial environment that they provide, and children's intrinsic and extrinsic spatial skills using structural equational modeling. Findings showed that mothers' spatial ability, mothers' toy choice, and the home intrinsic spatial environment did not significantly predict child spatial ability. Second, in a sample of 152 mothers of four- to six-year-old children, mothers' interest in STEM and spatial anxiety were examined in relation to the frequency of mother-child spatial play in the home setting. Findings showed that mothers' interest in STEM and general anxiety predicted mother-child spatial play, but not mothers' intrinsic spatial anxiety. This study adds to the current literature by exploring how mothers' characteristics, beyond spatial ability, relate to children's early home spatial environment. Additionally, it studies the development of both intrinsic and extrinsic spatial skills in young children. This dissertation is a first step toward identifying parent characteristics and practices that can be targeted for intervention as a mechanism for improving children's spatial ability. These findings suggest that mothers with low interest in STEM and/or high levels of general anxiety are prime candidates for participating in training in how to foster children's spatial skills at home through play. Further, these findings call for future work that measures the home spatial environment as spatial language production or quality of parent spatial support, instead of frequency of spatial play, and explores whether, and how, child and father characteristics contribute to the home spatial environment in addition to mother characteristics.

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I. INTRODUCTION

Spatial thinking includes many skills such as the ability to understand size, shape, location, direction and distance, to reorient and navigate in space, to use maps and diagrams, to mentally rotate objects and to recreate patterns (Sinton, Bednarz, Gersmehl, & Uttal, 2013). The ability to think spatially about the world helps us complete everyday tasks such as assembling furniture using an instruction booklet, packing luggage for an upcoming vacation, or using a map to locate a building on a university campus. In addition to being useful to us in our daily lives, individual differences in spatial thinking predict children's mathematical achievement (Gilligan, Flouri, & Farran, 2017; Gunderson, Ramirez, Beilock, & Levine, 2012; Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014; Wong, 2017), children's science achievement (Hodgkiss, Gilligan, Thomas, Tolmie, & Farran, 2017; Hodgkiss, Gilligan, Tolmie, Thomas, & Farran, 2018) and later entry, and success, in Science, Technology, Engineering, and Mathmematics (STEM) disciplines (Lubinski, 2010; Wai, Lubinski, & Benbow, 2009).

The identification of factors that predict individual differences in spatial thinking is important because since spatial thinking is malleable (Cheng & Mix, 2014; Newcombe, 2010; Uttal et al., 2013), we can use this research to develop evidence-based interventions to improve STEM learning in typically underrepresented groups like women and minorities. To date, we know of several factors that contribute to the development of child spatial ability. These factors include motor skill (Frick & Mohring, 2016; Jansen, Kellner, & Rieder, 2013), working memory and executive function (Kaufman, 2007; Lehmann, Quaiser-Pohl, & Jansen, 2014; Wang and Carr, 2020), child and parent spatial language (Pruden, Levine, & Huttenlocher, 2011), spatial anxiety (Ramirez, Gunderson, Levine, &

Beilock, 2012), and spatial play (Gold et al., 2018; Levine, Ratliff, Huttenlocher, & Cannon, 2012; Nazareth, Herrera, & Pruden, 2013). There is little in the current literature explaining how parent characteristics beyond parental use of spatial language (Pruden et al., 2011) and parental gender stereotypes (Crowley, Callanan, Tenenbaum, & Allen, 2001; Wang & Degol, 2013) predict individual differences in parent's promotion of the home spatial learning environment and children's spatial ability despite theoretical motivation to investigate these relations.

The theory of academic socialization posits that parents' attitudes and practices provide the foundation for their child's performance in school (Taylor, Clayton, & Rowley, 2004). Specifically, parents' cognitions about school influence their parenting practices including their selection of activities for their child, which then influence their child's academic achievement (Elliott & Bachman, 2018; Taylor et al., 2004). Further, the idea that parents play an important role in the home learning environment is also supported by Vygotsky's sociocultural theory which proposes that cognitive development occurs through social interactions between a less experienced individual (child) and a more experienced individual (parent). This theory suggests that not only are parents' selection of activities for their child important, but also that the frequency and quality of collaborative play and activities between child and parent can promote children's learning (Ramani & Siegler, 2014; Vygotsky, 1978).

Several research studies have shown that frequent exposure to spatial activities (i.e., blocks, puzzles) at home can yield to gains in children's spatial abilities suggesting that the home spatial environment is a direct predictor of child spatial ability (Casey, Andrews, Schindler, Kersh, Samper, & Copley, 2008; Jirout & Newcombe, 2015; Levine et al., 2012;

Oostermeijer, Boonen, & Jolles, 2014; Vander Heyden, Huizinga, & Jolles, 2017). Thus, it is possible that variation in the home spatial environment is a potential explanation for why children have different spatial ability level even prior to formal schooling. However, far less researched, is *why* there is variability among children's home spatial learning environments.

It can be hypothesized that mother characteristics can influence the home spatial learning environment that they provide for their children, and in turn, their spatial ability. This dissertation aims to understand whether, and to what extent, mother characteristics (i.e., spatial ability, spatial anxiety, and interest in STEM) relate to the mother's promotion of the home spatial learning environment and their child's spatial abilities. In Paper 1, we review research studies that examine the mechanisms that explain individual differences in children's spatial ability with a strong emphasis on parental characteristics and the home spatial learning environment. In Paper 2, we explore whether mother intrinsic and extrinsic spatial ability predicts child's intrinsic and extrinsic spatial ability directly and indirectly via variation in the home spatial environment. Finally, in Paper 3, we explore whether mothers' characteristics (i.e., interest in STEM, spatial anxiety) influence mothers' frequency of joint engagement in spatial activities in the home setting.

<u>Paper 1:</u> Individual Differences in Early Spatial Ability: A Review

Paper 1 reviews correlational and experimental research studies that describe mechanisms by which child spatial ability develops. The *Relational Developmental Systems* (RDS) framework which examines predictors of children's spatial development across biological, psychological, and cultural levels of analysis is proposed as a way to explain how individual differences in spatial ability emerge (Overton, 2014). Lastly, limitations of existing literature and directions for future research are discussed in depth.

<u>Paper 2:</u> Direct and indirect effects of mother spatial ability on child spatial ability: What role does the home environment play?

Paper 2 examines whether mother spatial ability directly and indirectly (via mother toy choice and frequency of joint spatial play with their child in the home setting) is predictive of child's spatial ability. A total of 165 mothers and their 4- to 6-year-old children were recruited to participate in a remote video session with an experimenter. Mothers were asked to complete the *Intrinsic Spatial Toy Preference Task,* the *Home Intrinsic Spatial Environment Questionnaire,* the abbreviated *Mental Rotation Test* (Peters et al., 1995; Vandenberg & Kuse, 1978), and the adapted *Spatial Scaling Task* (Frick & Newcombe, 2012). Children were administered the *Picture Rotation Task* (Quaiser-Pohl, 2003), the adapted *Spatial Scaling Task* (Frick & Newcombe, 2012), and the *Peabody Picture Vocabulary Test, Version 5* (*PPVT-5*; Dunn, 2019). This study is novel in that it is one of the first to examine mother spatial ability, the early home spatial environment, and children's spatial ability in one study, it explores the development of children's intrinsic *and* extrinsic spatial abilities, and data collection was conducted remotely.

<u>Paper 3:</u> Mothers' Interest and Anxiety in Relation to the Early Home Spatial Environment

Paper 3 focuses on potential factors that influence variation in the home spatial learning environment. Specifically, paper 3 investigates the relation between mothers' interest in STEM and mothers' spatial anxiety in relation to their promotion of the home spatial learning environment when accounting for mothers' highest level of education and mothers' general anxiety. A total of 150 mothers of 4- to 6-year-old children were asked to complete the adapted *Spatial Anxiety Questionnaire* (Alvarez-Vargas, Abad, & Pruden, 2020), the *Intrinsic Spatial Toy Preference Task*, the *Home Intrinsic Spatial Environment Questionnaire*, and the *Demographic Information Questionnaire*. This study provides insight about why some mothers engage in more spatial activities with their children than others and which mothers may benefit from training in how to create a high-quality home spatial learning environment.

Overall, the goal of this dissertation is to better understand the role that mothers and the early home spatial environment play in children's spatial learning and development. The findings of these studies advance developmental theory about spatial thinking, have important implications for parenting practices and early childhood education, and lay groundwork for future interventions and trainings for parents of preschool-aged children.

II. Individual Differences in Young Children's Spatial Ability: A Review

The ability to think spatially about the world is necessary to complete many everyday tasks including packing a carry-on suitcase, interpreting a graph, trying a new route without the help of a map or GPS, or using a campus map to locate a building. Further, correlational and experimental research studies have shown that spatial skills are associated with math achievement (Eilam & Alon, 2019; Gilligan, Flouri, & Farran, 2017; Gilligan, Hodgkiss, Thomas, & Farran, 2018; Jirout, Holmes, Ramsook, & Newcombe, 2018; Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014; Wong, 2017) and science achievement (Ganley, Vasilyeva, & Dulaney, 2014; Hodgkiss, Gilligan, Tolmie, Thomas & Farran, 2018; Tracy, 1990) in childhood, and entry into Science, Technology, Engineering, Mathematics (STEM) careers in adulthood (Lubinski, 2010; Wai, Lubinski, & Benbow, 2009). This relation found between spatial ability and STEM success persists even when accounting for other forms of intelligence such as verbal and mathematical intelligence (Lubinski, 2010; Wai et al., 2009).

Theoretical and data-driven evidence support the categorization of spatial abilities into two types; intrinsic and extrinsic (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Mix, Hambrick, Satyam, Burgoyne, & Levine, 2018). Intrinsic spatial thinking consists of the examination of the relations within an object or between an object's constituent parts (Mix et al., 2018; Newcombe & Shipley, 2015). This includes studying characteristics of objects such size or orientation, as well as manipulating shapes and objects through mental transformation and rotation (Hegarty et al., 2006; Uttal et al., 2013). Examples of intrinsic spatial tasks include mental rotation tasks, mental transformation tasks, and block design tasks. Extrinsic spatial thinking involves the relations between two or more objects in both real and imagined spaces or determining the relation between an object and its environment (Atit, Uttal, & Stieff, 2020; Mix et al., 2018; Newcombe & Shipley, 2015). Examples of extrinsic spatial tasks include navigation tasks, perspective-taking tasks, proportional reasoning tasks, and spatial scaling tasks.

Individual differences in children's spatial ability, both intrinsic and extrinsic, emerge in early childhood, with preschool- and elementary-aged children showing a great deal of variability on spatial tasks (Frick & Newcombe, 2012; Hawes, LeFevre, Xu, & Bruce, 2015) making the preschool and elementary school years a sensitive period for spatial development and a target age group for training and intervention. Both individual differences (Hawes et al., 2015) and sex differences favoring males (Casey et al., 2008; Levine, Huttenlocher, Taylor, & Langrock, 1999) in intrinsic spatial thinking have been documented as early as four years of age. Similarly, individual variability in extrinsic spatial thinking has been found as early as ages 3 to 6 years (Frick & Newcombe, 2012).

Fortunately, spatial skills have been found to be malleable, meaning that they can be improved through intervention (Newcombe, 2010; Sorby & Baartmans, 2000; Sorby, Casey, Veurink, & Dulaney, 2013; Stieff & Uttal, 2015; Uttal et al., 2013). A wide variety of spatial interventions including extensive practice of a specific spatial skill and academic coursework have yielded significant gains in both intrinsic spatial ability (Cornu, Schiltz, Pazouki, & Martin, 2019; Hawes, Moss, Caswell, Naqvi, & MacKinnon, 2017) and extrinsic spatial ability in children (Eilam & Alon, 2019). For example, in a 32-week classroom-based intervention for grades Kindergarten to 2, children in experimental classrooms exposed to a variety of spatial lessons and activities as part of the mathematics curriculum demonstrated improvements in spatial language, visual-spatial geometric reasoning, and mental rotation compared to the children in the control condition who received traditional mathematics instruction (Hawes et al., 2017). Interventions have also been successful in improving extrinsic spatial abilities (Eilam & Alon, 2019). A weekly training session consisting of both theory and skill practice led to a moderate, positive effect on first and fourth grade students' perspective taking ability (Eilam & Alon, 2019).

Further, spatial interventions have not only yielded domain-specific gains in spatial ability but have also produced transfer effects to a related domain, mathematics (Cheng & Mix, 2014; Cheung, Sung, & Lorenco, 2019; Lowrie, Logan, & Ramful, 2017). Cheng and Mix (2014) conducted an experiment comparing calculation ability in 6-to 8-year-old children that had either been assigned to a 40-minute mental rotation training session or a crossword puzzle activity. Children who received the single session of mental rotation training showed substantial gains in calculation scores, specifically on the missing term problems (Cheng & Mix, 2014). Similarly, in another training study, 6- and 7-year-olds either completed a 1-week online mental rotation training or literacy training. The children who received mental rotation training, not only improved their mental rotation ability, but also performed better on the math assessment than the children in the literacy group (Cheung et al., 2019). These studies suggest that early interventions targeting spatial skills are not only effective for improving spatial skills, but mathematical skills as well. Thus, identifying factors that contribute to spatial ability can lay the groundwork for evidence-based intervention and modification of existing curriculum to increase achievement in STEM in young children. The development of early interventions are crucial since the benefits of spatial training are greater when the intervention occurs earlier in life (Uttal et al., 2013).

The Current Review

In this paper, we argue that individual differences in children's spatial ability may be due, in part, to differences in characteristics of children, teachers, and parents and the environment to which children are exposed. First, we use the Relational Developmental Systems (RDS; Overton, 2013; Overton, 2014; Pruden et al., 2020) framework to explain how individual differences in spatial ability emerge. We then examine recent empirical work addressing how several factors relate to individual differences in children's spatial ability. Finally, we discuss limitations of the existing literature on the development of young children's spatial ability and offer suggestions for future research.

Relational Developmental Systems Framework: A Modern Approach to the Study of the Development of Spatial Ability

A modern approach to studying spatial development is through the relational developmental systems framework, which holds that development emerges from complex co-acting systems operating at multiple levels of analysis (over time) including at the biological, psychological, and cultural levels (Overton, 2014). We will use this framework to guide our discussion of the mechanisms that explain individual differences in the development of spatial ability in young children. This paper aims to examine behavioral evidence in the form of correlational, experimental, and intervention research considering several predictors of children's spatial development across three levels of analysis: biological (i.e., parent spatial ability, child motor skill), psychological (i.e., child working memory and executive function, child spatial play, child spatial anxiety), and cultural (i.e., teacher spatial competence and anxiety, parent use of spatial language, and parent promotion of the home spatial environment; see Figure 1). It is important to note that RDS posits that the development of spatial thinking occurs as a co-action among factors across all levels of analysis. In this review we only identify a handful of mechanisms and there are many more to consider (i.e., child interest, opportunities for spatial learning in the classroom and the school). In order to fully understand how spatial development develops, it would be necessary to consider all these co-actions over time. Additionally, the way these mechanisms are characterized are not fixed. For example, parent spatial anxiety can be considered biological or cultural depending on the author's specific research question.

Biological Level of Analysis

Parent Spatial Ability

It is possible that spatial ability level can be transmitted between generations from parents to children. Domain-general research has shown that an individual's general cognitive ability is related to their parents' general cognitive ability, even when controlling for variables like educational attainment and socio-economic status (Anger & Heineck, 2010). Intergenerational transmission of specific abilities including mathematics (Braham & Libertus, 2017) and reading (van Bergen, van Zuijen, Bishop, & de Jong, 2017; Wadsworth, Corley, Hewitt, Plomin, & DeFries, 2002) have also been found.

Only a handful of research studies have addressed whether parents' own spatial ability relates to their children's spatial abilities. A significant, direct pathway between maternal intrinsic spatial ability (mental rotation) and daughter's intrinsic spatial thinking (mental rotation, mental transformation, and block design) has been found (Dearing et al., 2012) and since replicated using a different sample (Casey, Dearing, Dulaney, Heyman, & Springer, 2014). It is important to note that only mothers were used in these previous studies, and to our knowledge, no studies exist exploring the relation between father and child spatial ability. Notably, including only one parent in the investigation gives us an incomplete picture of how the home environment affects the development of spatial abilities since we are lacking information about the father's contribution. Further, these findings only examine intrinsic spatial abilities (i.e., mental rotation, mental transformation, block design) and neglect extrinsic spatial abilities (i.e., perspective taking, spatial scaling, navigation). Lastly, these studies only show a direct effect of maternal spatial ability on child spatial ability. Future work should consider how maternal spatial ability indirectly affects child spatial ability through mechanisms such as provision of spatial toys/activities in the home and joint spatial play and activities. Behavioral genetic theory suggests that children's traits are not only influenced by the overlap between parents' and children's genes but also by the rearing environment (Hart, Little, & van Bergen, 2019; Plomin, DeFries, & Loehlin, 1977; Scarr & McCartney, 1983). For instance, if a mother is an excellent reader, she may read more to her child, buy more books for the home, take her child on more trips to the library, leading to her child becoming an excellent reader as well through a combination of both genetic and environmental factors. Moreover, parent spatial ability could be related to the level of support that a parent can provide. Parents with higher spatial ability may provide higher quality interactions during joint spatial play to facilitate their child's spatial learning than parents with lower spatial ability (Casey et al., 2014). Although the initial finding that mother and child intrinsic spatial ability are related is intriguing, there is much work to be done in this line of research.

Motor Skill

There is reason to believe that motor skill is related to the development of spatial thinking. Research in infancy and childhood suggests that motor skill acquisition goes hand-in-hand with cognitive achievements, resulting in the co-development of motor and cognitive, especially spatial, ability (Cameron, 2018). A possible explanation for this is that school requirements in early childhood education are heavily dependent on motor skill, especially fine motor skill, which makes school easier for students who have more advanced motor development (Cameron, 2018). For instance, a child needs to have the strength and motor ability to adequately hold a pencil to be able to write letters and numbers. Further, deficits and delays in motor development are often correlated with deficits and delays in cognitive development. This is evident from the frequent presence of motor impairments in children diagnosed with cognitive disorders (i.e., dyslexia, specific language disorder, attention deficit hyperactivity disorder (ADHD), and Autism Spectrum Disorder; Diamond, 2000).

Several studies show, via correlational designs, that child motor skill is associated with performance on measures of intrinsic spatial ability. For example, balance is predictive of mental rotation task performance in 3- to 6-year-olds (Lehmann et al., 2014), 5- to 6-year-olds (Jansen & Heil, 2010), and 6-year-olds (Frick & Mohring, 2016). A relation between motor skill and mental rotation performance is also evidenced by comparing individuals with high levels of motor experience to those with low levels of motor experience. In one study, trained divers with extensive motor practice demonstrated faster reaction times in solving items on a mental rotation task than non-athletes (Feng, Zhang, Ji, Jia, & Li, 2017). The results of this study suggest that hours of sports practice predict mental rotation ability. Relatedly, 8th to 10th grade students enrolled in anenhanced physical education program that received two hours of physical education as wellas sports team practice for an additional ten hours a week had higher mental rotation test scores than their fellow classmates who opted only for the standard two 90-minute sessions of physical education per week (Jansen, Ellinger, & Lehmann, 2016).

Training studies generally find that by improving children's motor ability you can improve their mental rotation scores as well. Gains in mental rotation performance have been achieved through interventions that emphasize juggling (Jansen, Lange & Heil, 2011), physical education (Jansen, Kellner, & Rieder, 2013), dance (Jansen et al., 2013; Jansen & Richter, 2015), wrestling (Moreau, Clerc, Mansy-Dannay, & Guerrien, 2012) and general motor training (Bluchel, Lehmann, Kellner, & Jansen, 2013; Pietsch, Bottcher, & Jansen, 2017).

Associations between motor skill and spatial ability exist beyond just mental rotation. Although the line of research investigating the relation between motor skill and extrinsic spatial abilities is relatively new, there are a few studies showing that motor skills are associated with extrinsic spatial abilities such as navigation and perspective taking. In one study, stronger fine motor skills were associated with fewer errors on a route learning task, even after controlling for age, in a typically-developing sample of children between the ages of 5 and 11 years (Farran, Bower, Karmiloff-Smith, D'Souza, Mayall, & Hill, 2019). Another study demonstrated that balance, measured as walking heel-to-toe and toe-to-heel, was predictive of errors on a perspective taking task in typically developing 8- to 16-year-olds (Cardillo, Erbi, & Mammarella, 2020). Despite the abundance of evidence that shows a link between motor skill and mental rotation ability, more research needs to be conducted exploring the relation between motor skill and extrinsic spatial abilities like navigation, perspective taking, and spatial scaling.

Psychological Level of Analysis

Working Memory and Executive Functions

Executive functions (inhibition, cognitive flexibility, and working memory) are higher-order cognitive processes involved in formulating and carrying out goals (Miyake et al., 2000). Inhibition is the ability to selectively attend to specific stimuli while suppressing distracting stimuli that are irrelevant to the task at hand (Diamond, 2013). Cognitive flexibility is the ability to adjust to changing demands (Diamond, 2013). Lastly, working memory is the ability to maintain and manipulate information for a short period of time (Baddeley, 1992; 2000). Executive functions are thought to play a role in explaining individual differences in spatial ability. So far, most research has focused on the relation between one specific component of executive functioning, working memory, and its relations to spatial ability. Working memory appears to be involved in storing the visual representation of the original stimulus while it is being rotated in one's imagination during mental rotation tasks (Hyun & Luck, 2007). Research studies in the adult literature have established a working memory-spatial ability link reporting that working memory capacity is related to reaction time on mental rotation tasks (Goodmon et al., 2019), is related to accuracy on mental rotation tasks (Wang & Carr, 2020), partially mediates sex differences typically found in mental rotation tasks (Kaufman, 2007), and influences the types of strategies used to solve spatial tasks (Wang & Carr, 2014). Research studies examining the relation between working memory and spatial ability in children are sparse, but emerging. Utilizing a battery of working-memory tasks, Lehmann, Quaiser-Pohl, and Jansen (2014) found that over 55% of the variance in 3- to 6-year-old children's mental rotation scores was accounted for by their performance on working memory tasks. Similarly, in children aged 10- to 12-years-old, performance on a working memory task seemed to be significantly related to children’s mental rotation (He, Li, & Yin, 2019).

Further, there is evidence that executive functions beyond working memory contribute to individual differences in spatial ability in both children and adults. In a research study assessing 131 four- to six-year-olds using a battery of spatial, executive function, and general intelligence tasks, results showed that general executive functioning (combined inhibition, cognitive flexibility, and working memory) was a significant predictor of intrinsic spatial ability (i.e., mental rotation, block design), as well as extrinsic spatial ability (i.e., spatial scaling; Garcia, Pruden, & Dick, 2021). In a sample of slightly older children (8- to 10-years-old), two measures of inhibition (Stroop, Go/No-Go) were found to be predictive of mental rotation ability (He et al., 2019). Lastly, in a sample of 167 undergraduate college students, Miyake and colleagues (2001) found that executive functions were direct predictors of three spatial abilities (spatial visualization, spatial relations, perceptual speed). To date, most of the work has been correlational, and with adult populations, thus experimental studies with children are needed to infer a causal effect between executive function and spatial ability. Studies aimed at disentangling the causal effects of executive function on spatial ability would also help us answer the question of whether working memory and/or executive function training in children couldyield far transfer effects in spatial ability?

Spatial Play

There is no doubt that play is an important contributor to child development. Free play, in which children initiate and direct their own play without intervention from adults, can support children’s learning in general (Hirsh-Pasek & Golinkoff, 2008; Weisberg, Kittredge, Hirsh-Pasek, Golinkoff, & Klahr, 2015). More specifically, certain types of toys provide children with the opportunity to practice their spatial skills (Zimmermann, Foster, Golinkoff, & Hirsh-Pasek, 2019). Thus, spatial play can support the development of children's spatial thinking (Abad, 2018). For example, puzzles require children to physically rotate puzzle pieces in order to fit them together and subsequently complete the puzzle. Spatial development experts have identified many toys and activities such blocks, puzzles, marble runs, mazes, and stacking games that are correlated with high performance on spatial tasks (Abad, 2018).

A longitudinal study following 197 preschool children for two years showed that children's interest in spatial activities positively predicted subsequent growth of spatial ability suggesting that fostering young children's interest in spatial activities is one potential mechanism to promote spatial ability development (Xiao & Zhang, 2021). Through retrospective studies, we have also established a relation between engagement in spatial activities in childhood and adult spatial ability. Doyle and colleagues (2012) found that participants who engaged in spatial activities in childhood, performed better on two intrinsic spatial tasks as adults, the Mental Rotation Task and the Water Level Task. In another retrospective study, it was found that the number of masculine-typed spatial activities that participants reported to engage in during childhood mediated the relation between sex and mental rotation task scores (Nazareth, Herrera, & Pruden, 2013). Lastly, Moe and colleagues (2018) found that women pursuing STEM degrees preferred spatial toys in childhood when compared to women pursuing non-STEM degrees. Because access to and frequency of play with is greatest with a blocks, puzzles, and computer and video games (Abad, 2018), we will focus our discussion on these spatial toys as potential mechanisms for spatial development.

Building blocks have been shown to benefit children's spatial skills. Casey and colleagues (2008) designed two block building activity interventions, one with a storytelling context and one without, and found that both types of block building activity interventions yielded improvement on block design scores in kindergarten students. The finding that block play is associated with spatial ability is important because research has shown that boys play with blocks more frequently than girls (Jirout & Newcombe, 2015). This is a call-to-action for parents to encourage their children, especially their girls, to play with blocks, as there may be direct benefits to their developing spatial abilities.

Jirout and Newcombe (2015) observed a correlation between parent-reported frequency of spatial play at home and child block design scores (intrinsic spatial ability) in a large, nationally representative sample of 4- through 7-year-old children. Children whose parents reported frequent puzzle, block, and board game play at home exhibited higher spatial skills than children who engaged in these spatial activities less frequently. A similar relation has also been found between puzzle play and mental transformation ability, another type of intrinsic spatial ability. Levine and colleagues (2012) observed parent-child dyads at home for 90 minutes at six time points between 2 and 4 years of age and found that children who were observed playing with puzzles at home more frequently, performed better on the spatial transformation task (Levine et al., 2012).

As access to digital devices is increasing among children and digital play is becoming an increasingly large part of children's lives, recent lines of research have expanded their definition of spatial play beyond physical activities, like blocks and puzzles, to include digital play, like computer and videogames. Correlational and experimental studies show that computer and videogame experience are related to performance on spatial tasks (Feng, Spence, & Pratt, 2007). Quaiser-Pohl and colleagues (2006) investigated whether computer-game experience was related to mental rotation test (MRT) scores in a sample of 861 students ages 10 to 20. Results indicated that a relation exists between computer-game experience and mental rotation performance only for boys (Quaiser-Pohl et al., 2006). Moreover, computer and video game experience mediated the sex difference favoring males in mental rotation suggesting that offering computer and video game experiences to females may yield improvement in mental rotation scores in females (Terlecki & Newcombe, 2005). Several training studies seem to suggest that playing video games has far transfer effects on spatial performance. Feng and colleagues (2007) found that after 10 hours of training with an action video game, undergraduate students displayed substantial gains in spatial attention and mental rotation compared to participants in the control group. Similarly, Cherney (2008) found that four hours of computer game play were enough to yield gains in mental rotation ability in undergraduate students, especially in females. This may be because females typically have lower levels of computer and video game experience than men so have more room for improvement. It is important to note that not all computer and video game play leads to improvement in spatial ability. For instance, only instruction in “Tetris” which involves rotation of shapes similar to the skills required in a mental rotation test, and not instruction in “Carmen San Diego” led to increased mental rotation scores in a sample of third grade students (De Lisi & Wolford, 2002). Additional research is needed to determine which specific types of computer and video games yield gains in spatial ability and whether these gains are seen in both males and females.

Most research studies regarding spatial play explore its connection with the development of intrinsic spatial abilities (i.e., mental rotation, mental transformation, block design). The reason may be that these types of toys (i.e., blocks, puzzles) allow for practice manipulating objects which is the skill typically assessed in intrinsic spatial tasks, thus they may not be useful for the development of extrinsic spatial abilities. Recent studies suggest that activities outside of the home like wayfinding and roaming may be more predictive of extrinsic spatial abilities like navigation and perspective taking (Nazareth, Weisberg, Margulis, & Newcombe, 2018; Schug, 2016; Vieites, Pruden, & Reeb-Sutherland, 2020). Yet, little is known about these links between real-world roaming and extrinsic spatial abilities. Future research studies should continue to examine what types of spatial activities and experiences can foster extrinsic spatial ability as this line of research is significantly under researched. Additionally, there is a need for research that assesses whether promoting spatial activities in childhood via intervention leads to increased spatial ability later in adolescence and adulthood, calling for the need to conduct longitudinal research.

Spatial Anxiety

Spatial anxiety refers to feelings of worry and apprehension triggered by tasks that require spatial thinking (Lauer, Esposito, & Bauer, 2018; Lawton, 1994; Malanchini et al., 2017; Ramirez et al., 2012). There are two types of spatial anxiety, large-scale anxiety and small-scale anxiety (Malanchini et al., 2017). Large-scale anxiety is experienced in situations that require navigational skills such as navigating in a new city or finding your way home without the aid of a map/GPS (Lawton, 1994). Small-scale anxiety can be elicited in situations such as building a tower using a model (Lauer et al., 2018; Ramirez et al., 2012). In some cases, individual differences in spatial ability are not brought about by an individual's actual potential, but rather by spatial anxiety. Spatial anxiety is inversely related to spatial ability; thus, individuals with higher levels of spatial anxiety typically have lower levels of spatial ability (Malanchini et al., 2017).

For example, large-scale spatial anxiety has been shown to be correlated with the reduced use of effective navigational/route strategies in adults (Lawton, 1994; Vieites, Pruden, & Reeb-Sutherland, 2020). As a participant's report of large-scale spatial anxiety increases, so do the number of navigation errors made on a navigation task (Hund & Minarik, 2006). Total spatial anxiety, measuring both large-scale and small-scale anxiety, is correlated to children's spatial reasoning. Greater spatial anxiety was associated with lower mental rotation task scores in 394 elementary-school students (Lauer et al., 2018). Spatial anxiety can also play a moderating role. In a sample of 182 Hong Kong preschoolers, Wong (2017) found that spatial anxiety moderated the relation between spatial ability and counting ability. More specifically, the relation between spatial ability and counting ability was weaker in boys with high levels of spatial anxiety. Therefore, it is plausible that reducing spatial anxiety is a potential way to increase spatial performance in children. Future work should look at factors that predict the development of spatial anxiety (i.e., gender stereotypes, lack of engagement in spatial activities) in order to find strategies that are effective in reducing spatial anxiety in children.

Cultural Level of Analysis

Teacher Spatial Competency and Spatial Anxiety

Teacher characteristics such as competence, interest, and attitudes toward a subject can influence their teaching efficacy, and in turn, their student's learning of the subject (Burte, Gardony, Hutton, & Taylor, 2020). This is especially true for elementary school teachers who, as opposed to high school or college instructors, must teach all subjects, even those that they do not like. Teachers who do not feel competent enough to teach spatial tasks or who have high levels of spatial anxiety may struggle with providing their students with effective opportunities for spatial learning or avoid them altogether. Further, since spatial thinking is not a stand-alone subject in school like mathematics or reading, teachers can choose to avoid incorporating spatial activities in the classroom, and it is presumed that teachers with low levels of spatial competence or high levels of spatial anxiety do this, which in turn, adversely affects students' spatial ability (Gunderson, Ramirez, Beilock, & Levine, 2013).

Not surprisingly, teachers' ratings of spatial competency and total spatial anxiety are inversely related (Burte et al., 2020). Thus, it is plausible that teachers who experience high levels of spatial anxiety may inadvertently negatively impact students' spatial learning. In one study, 1st and 2nd grade teachers' large-scale spatial anxiety significantly predicted students' end-of-the-year mental rotation scores such that students of teachers with high levels of spatial anxiety performed worse on mental rotation tasks than students of teachers with low levels of spatial anxiety (Gunderson et al., 2013). Future research is needed to test the underlying mechanisms between the relation between teacher spatial anxiety and children's intrinsic spatial ability. Additionally, to our knowledge, there is no research examining teachers' spatial anxiety in relation to children's extrinsic spatial ability.

Recent research suggests that teachers' spatial anxiety can be reduced through a week-long professional development intervention where teachers learn about how to teach spatial reasoning and collaborate with researchers to develop spatial activities for the classroom (Ping et al., 2011). More applied research is needed to determine effective ways to reduce teachers' spatial anxiety. Lastly, the relation between teacher's competence in teaching spatial concepts and children's' spatial ability is under researched although there is reason to believe that teachers' competence can influence children's spatial learning (Burte et al., 2020).

Production of Spatial Language

Variability in the diversity and amount of spatial language that infants and children hear is another candidate mechanism that contributes to individual differences in early spatial ability (Casasola et al., 2020; Pruden et al., 2011). Spatial language includes a large lexicon that communicates the spatial dimensions (e.g., "big," "short," "thin"), shapes (e.g., "circle," "cube," "shape"), spatial features and properties (e.g., "edge," "round," "corner"), locations and directions (e.g., "on," "near," "North"), and orientations (e.g., "upside down," "turn," "rotate") of objects, people, and points in space. When individuals use this domain-specific vocabulary with infants and children, it draws attention to and strengthens encoding of spatial information that might otherwise have been overlooked (Casasola, 2005; Casasola et al, 2009; Hermer-Vasquez et al., 2001; Lowenstein & Gentner, 2005) which may, in part, lead to varied developmental cascades that affect individual differences in spatial abilities. Pruden and colleagues (2011) conducted a longitudinal investigation that examined caregivers' language input with their children from 14 months until 46 months. The families were videotaped in their home environment for 90 minutes once every four months, then children were given a series of spatial tests when they were 54 months. They found that caregivers who used more spatial language during this period had children who also used more spatial language, and in turn, children who had used more spatial language demonstrated better performance on the spatial tests at 54 months (Pruden et al., 2011). The finding that children's production of spatial language may be a crucial component of spatial skills was also demonstrated by Polinsky and colleagues (2017). They observed that even the spatial language that children produced while they briefly interacted with a parent at a museum exhibit predicted individual differences in their spatial skills. Children completed a puzzle that required rotation at pretest, engaged in a 3-minute, audio-recorded interaction with their parents at a block wall museum exhibit, then completed similar puzzles at posttest. They found that children's spatial language production predicted how rapidly they completed the puzzles at posttest.

Using an experimental design, Casasola et al. (2020) tested whether there is a causal relation between spatial language and children's spatial skills. Fifty preschool-aged children (age 4 years) engaged in five 12-minute constructive play sessions weekly over an average of four weeks. They were randomly assigned to either the control condition in which they engaged in play activities while receiving no spatial language input from experimenters, or the experimental condition in which they engaged in identical activities but received a rich amount and variety of scripted spatial language input. Mental rotation and spatial vocabulary were assessed at baseline and several days after the play sessions ended. Casasola et al. (2020) found that children who heard more spatial language had significantly higher gains in mental rotation scores when compared to the children in the control group. While establishing a causal link between spatial language and spatial skills is a critical step in understanding the role that spatial language plays in individual differences in early spatial abilities, trained experimenters provided children with copious amounts of spatial language. Future research will need to address whether findingsreplicate outside of the lab with caregivers and early childhood educators. Moreover, the directionality and mechanisms of change will need to be further outlined using either experimental or longitudinal studies.

Although caregivers have been shown to naturally use more spatial language when engaging in structured, constructive play relative to free play (Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, & Lam, 2011), a constructive context is not necessary for providing significant spatial language input. Casasola et al. (2020) assessed the impact of spatial language exposure on children's spatial skills using activities that were constructive (e.g., Legos, magna-tiles, and block building) and nonconstructive (e.g., shape scavenger hunt, making a shape collage, and connect-the-dots) in nature, and found that the constructive context of the activities did not interact with experimenter spatial language input in promoting children's mental rotation abilities. They concluded that the key component for increasing children's mental rotation skill was not the particular type of constructive play, but rather the enriched exposure to spatial language that accompanied these play activities (Casasola et al., 2020).

There appear to be significant differences in the spatial language that parents use with their young children such that boys are exposed to more spatial language than girls early on, and that exposure relates to individual differences in the development of children's early spatial abilities (Pruden & Levine, 2017; Pruden et al., 2011; Ralph et al., 2020). Pruden and Levine (2017) demonstrated that parents of 14- to 46-month-olds use significantly more spatial language over time with boys than girls, and Ralph and colleagues (2020) recently replicated these findings in their investigation of whether the spatial language that mothers use with their preschool and kindergarten-aged children differ by gender and grade level. Fifty-two children between four and six years of age and their mothers participated in this study (Ralph et al., 2020). The researchers assessed the spatial language of the dyad as they played with colorful magnetic tiles (similar to magna-tiles) for eight minutes. The children also completed a task that assessed mental rotation. Ralph et al. found that for children who were in preschool, mothers used more spatial language with boys than with girls, replicating the work of Pruden and Levine. Pre-k boys produced more spatial language than their female peers. Interestingly, the reverse gender difference was found with the kindergarten and first grade children such that mothers used significantly more spatial language with girls than with boys. Why do we see such a shift in parents' spatial language use? The researchers speculated that children's exposure to spatial language in the kindergarten curriculum leads them to produce this language at home, which in turn, influences their mothers' spatial language production. Future work should examine cultural influences that might influence parents' differential spatial language use with their daughters and sons, and to what extent this impacts the developmental trajectories of early spatial abilities. Finally, research that examines the relation between spatial language and spatial skills has focused on small-scale spatial skills such as mental rotation, but the extent to which spatial language is related to individual differences in large-scale spatial skills such as wayfinding and spatial scaling is not well understood and should also be the focus of future work.

Promotion of the Home Spatial Environment

Since spatial thinking is not formally taught in school settings and children spend a large percentage of their time outside of school, we must consider the home as an important context for spatial development (Meltzoff, Kuhl, Movellan, & Sejnowski, T., 2009; Zimmermann et al., 2019). The engagement of home-based activities that promote spatial thinking and are likely to foster spatial development will be referred to as the home spatial environment (HSE) to be consistent with work done in the mathematics and literacy fields. Parents' practices that expose children to spatial activities at home, as well as the quality of support during engagement in joint spatial play, can influence a child's spatial ability. Children can benefit greatly from guided play in which children engage in fun activities with the guidance of their parents or a more knowledgeable peer (Hirsh-Pasek & Golinkoff, 2008; Zimmermann et al., 2019). In fact, guided play has better learning outcomes than free play (Weisberg et al., 2015). These joint learning activities offer adults with an opportunity to provide children with new information to support their development and increase their understanding (Casey et al., 2014; Ramani & Siegler, 2014). High quality, goal-oriented spatial play also elicits spatial language from parents which can be advantageous for the child's spatial development (Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, & Lam, 2011). Casey and colleagues (2014) investigated whether maternal support during joint spatial play partially explained the association between mother and daughter spatial skills. In this study, 162 mother-daughter dyads were videotaped participating in a joint origami activity and mothers were rated on quality of assistance (i.e., the structure that the mother provides in order to enable her daughter to be successfulin solving the task) and stimulation of cognitive development (i.e., the extent to which the mother uses the task as a cognitive learning opportunity for her daughter). Maternal supportive interactions during joint spatial engagement played a mediating role between maternal spatial skills and daughter spatial skills suggesting that mothers who had high spatial ability provided higher quality supportive interaction to their daughters (Casey et al., 2014). Research studies need to be conducted to determine whether guided play is important in the development of children's extrinsic spatial ability. We have discussed that both free and guided spatial play are associated with higher spatial ability (Jirout & Newcombe, 2015; Levine et al., 2012), but why do some parents provide more spatial toys and activities to their children than others? We discuss parent spatial ability, spatial anxiety, and interest in relation to parents' promotion of the home spatial environment.

It is possible that because parents with higher spatial ability are good at the skills that spatial activities require, they may be more likely to purchase more spatial toys for their children and engage their children more in spatial activities. Zippert and colleagues (2020) found that parents' rating of their spatial ability was related to parental report of frequency of engagement in spatial activities at home with their children (r = .39). Casey et al. (2014) propose that the quantity of spatial activities that children engage in is not as important as the quality of mothers' support during guided play and that mothers with higher spatial ability give better support during these interactions. More research is needed to examine the influence of mothers' spatial ability on both the frequency of engagement in joint mother-child play and the quality of support (i.e., spatial language, prompting children with stimulating questions) during these interactions.

Parent spatial anxiety, or negative feelings associated with completed spatial-related tasks, can lead to parents engaging less in spatial activities with their children or avoiding them altogether. In the similar domain of mathematics, it has been found that parents with higher levels of math anxiety engage in math activities and children's math homework at home less frequently than parents with low levels of math anxiety (Del Rio, Susperreguy, Strasser, & Salinas, 2017; Elliott, Bachman, & Henry, 2020; Kiss & Vukovic, 2021). The direct relation between parents' spatial anxiety and their engagement in joint spatial play with their children is not researched, but we can expect similar results.

Lastly, parent interest in spatial thinking can also influence the number of spatial toys and activities that they purchase for their children. Parents who are interested in a particular subject or domain tend to provide a support system at home that foster their child's own interest (Frenzel et al., 2010). Thus, we can hypothesize that parents who are interested in STEM may provide more spatial toys and activities to their children and dedicate more time to spatial activities at home. For example, parents who are interested in math, may purchase games and materials that involve math for their children (Jacobs & Bleeker, 2004). In the similar domains of math and science, parent interest has been correlated with frequency of engagement in math-related (Cheung, Dulay, & McBride, 2020) and science-related activities (Junge, Schmerse, Lankes, Castensen, & Steffensky, 2021) with their children. Research is needed to directly test whether an association exists between parents' interests in spatial thinking and children's spatial ability. Overall, more research is needed to show how the parent characteristics discussed (i.e., ability, spatial anxiety, interest) as well as those not discussed in this review (i.e., parental overall involvement, socioeconomic status) influence the number of spatial toys that they buy for their children, the frequency of joint spatial play with their children, and the quality of guided play.

Conclusions

Knowledge of the factors that influence spatial development open the field to many new lines of research and interesting research questions. It is suggested that we consider using bio-ecological approaches such as Relational Developmental Systems Theory to study spatial development in order to better understand the contributions of both genetics and early environments to the development of spatial skills (Casey et al., 2014; Dearing et al., 2012; Pruden et al., 2020). Relational Developmental Systems Theory posits that many factors across many levels of analysis play a role in determine spatial thinking (Overton, 2014). Thus, we should explore more closely how the relation between one factor (i.e., parental spatial ability on child spatial ability) changes in the presence of other factors (i.e., participation in spatial activities, exposure to spatial language). Mediation (a third, single factor explaining some of the effect found between the independent and dependent variables) and moderation (a factor that influences the independent variable in such a way that the relation between the independent variable and the dependent variable are conditional on the value of the moderator) pathways should be employed more often to explain spatial development.

Limitations of Existing Literature and Future Research

In this review, we discussed several evidence-supported mechanisms by which individual differences in children develop, however, many questions about how these mechanisms influence the development of spatial abilities remain unanswered. First, the majority of these factors (i.e., parent spatial ability, children's free and guided spatial play) have been examined in relation to the development of intrinsic spatial thinking (i.e., mental transformation/rotation) and have largely ignored the development of extrinsic spatial thinking (i.e., spatial thinking, perspective taking). Given the evidence that extrinsic spatial thinking also contributes to math and science learning and achievement (Jirout et al., 2018; Hodgkiss et al., 2017; Hodgkiss et al., 2018; Wong, 2017), we should look into early childhood experiences that contribute to the development of extrinsic spatial abilities in addition to intrinsic spatial abilities. We could start doing this by examining whether factors that predict intrinsic spatial thinking (i.e., parent spatial ability, children's executive function skills) are also important in the development of extrinsic spatial abilities, or whether extrinsic spatial abilities develop by different mechanisms.

Second, most of the research investigating factors that influence spatial development are correlational in nature, therefore no claims can be made about cause and effect. More studies should introduce an experimental manipulation or an intervention in order to be able to infer causality. For example, if many correlational studies have shown an association between exposure to spatial language and child spatial ability (Pruden et al., 2011; Polinsky et al., 2017), the field should move towards developing easy to implement interventions such as reading books that highlight spatial language to children and determine whether the increase in exposure to spatial language yields gains in child spatial ability. To our knowledge, there is only one study that demonstrates causal links between increased spatial language and children's spatial abilities (Cassasola et al., 2020). It is important to note that this study uses trained experimenters and experimental/interventions designs with parents and teachers are still needed. There is a great need for translational research that uses the findings from basic research to solve practical problems such as increasing STEM interest and ability in children.

Third, most research studies discussed in this paper only examine children's spatial abilities at one time point which goes against the Relational Developmental System's tenet that development is dynamic and should be approached using a lifespan approach. For example, in order to examine the influence of children's early spatial play on children's later spatial ability we should follow individuals to determine whether engagement in spatial activities in the preschool years relates to their spatial abilities in elementary school, high school, and college. A longitudinal approach would be beneficial for several reasons.

For one, it would help us better understand how early life experiences affects later life outcomes, not only concurrent spatial ability. Additionally, it would give us insight on the order in which events occur (i.e., does spatial skill or engagement in spatial activities come first?) in order to determine causation. Longitudinal studies are necessary to contribute to our knowledge of spatial development across the lifespan. Most studies that look at early childhood experiences and later spatial ability are retrospective and rely on participant recall which may be flawed and affected by responder bias.

Lastly, analysis of the development of spatial ability in children from the cultural level is lacking. It remains unclear how parent characteristics beyond parental production of spatial language influence individual differences in children's spatial ability. Most of the research conducted focuses on child-level factors despite theoretical motivation to examine the influence of parents and other caregivers on children's spatial development. Theoretical and empirical work from the sociocultural perspective suggest that informal learning activities at home can contribute to individual differences in children's abilities even prior to formal schooling (Ramani & Siegler, 2014). The theory of academic socialization posits that parents' attitudes, parenting practices, and selection of activities for their children heavily influence their child's school performance (Elliott & Bachman, 2018; Taylor, Clayton, & Rowley, 2004). Similarly, Lev Vygotsky's sociocultural theory suggests that cognitive development occurs through social interactions between a less experienced individual, a child, and a more experienced individual, a parent, which in turn supports the idea that collaborative home-based activities between child and parent can promote a child's spatial learning (Ramani & Siegler, 2014; Vygotsky, 1978). Sociocultural theory and preliminary evidence that parent characteristics (Casey et al., 2014; Dearing et al., 2012) and home-based toys and activities (Casey et al., 2008; Jirout & Newcombe, 2008; Levine et al., 2012) provide the foundation for an interesting line of research. Future work should address the lack of literature on the influence of parents and the home environment on children's spatial cognition. Research studies could address questions such as: Do parents' spatial anxiety influence the frequency and quality of engagement in spatial activities with their children? Does frequency of spatial play at home relate to children's extrinsic spatial ability? Further, mediation, moderation, and structural equational models could help examine how parents' characteristics influence the home spatial environment, and in turn, children's spatial ability.

Not only should future work approach child spatial development using a Relational Developmental Systems approach which examines multiple co-acting factors throughout the lifespan as stated above, but it should also focus on practical implications for parents and teachers. Future research should examine how both formal and informal learning experiences shape spatial learning. Practical applications of this line of work could include teaching teachers about spatial thinking and pedagogical activities and materials that support its development (Newcombe, 2010). Although there is an abundant amount of evidence that spatial abilities are important to math and science learning, the teaching of these skills in formal school settings is often minimized in early school settings or disregarded entirely. Previous classroom-based interventions have focused on modifying the math curriculum to add spatial lessons (Hawes et al., 2017), but other possible interventions could include training teachers on the importance of guided spatial play, showing teachers how to facilitate guided spatial play effectively (Zimmermann, Foster, Golinkoff, Hirsh-Pasek, 2019) or training teachers so that they are confident in teaching spatial skills and less spatially anxious.

In addition to correlational research examining the relation between spatial toys and activities at home and children's spatial ability, we should consider designing home interventions that can easily be administered by parents to improve children's spatial skills. For example, researchers can target parents and teach them the importance of spatial learning and how to support spatial learning at home through spatial language and joint spatial play and see whether they are effective in improving home spatial environments (proximal effects) and whether improvement in home spatial environments lead to increased spatial ability in children (distal effects).

In conclusion, the field should move away from examining how one factor influences children's spatial ability and instead investigate how multiple co-acting factors together, and over time, predict children's spatial ability (Overton, 2014; Pruden et al., 2020). More work is needed to determine how individual differences in both intrinsic and extrinsic spatial ability develop while taking into account biological, psychological, and cultural levels of analysis. This is essential in order to answer important developmental questions addressing how spatial development changes over time and what interventions are the most effective, and under what conditions, to improve children's spatial learning.

III. Direct and indirect effects of mother spatial ability on child spatial ability: What role does the home environment play?

Spatial thinking encompasses a variety of skills including the ability to understand size, shape, location, direction and distance, to reorient and navigate in space, to use maps and diagrams, to mentally rotate objects, and to recreate patterns (Sinton, Bednarz, Gersmehl, & Uttal, 2013). The ability to think spatially about the world helps us complete everyday tasks including assembling furniture using an instruction booklet, packing luggage, or using a map to locate a building. In addition to being useful to us in our daily lives, individual differences in spatial thinking predict children's mathematical ability/achievement (Gilligan, Flouri, & Farran, 2017; Gunderson, Ramirez, Beilock, & Levine, 2012; Verdine, Irwin, Golinkoff, & Hirsh-Pasek, 2014; Wong, 2017), children's science ability/achievement (Ganley, Vasilyeva, & Dulaney et al., 2014; Hodgkiss, Gilligan, Tolmie, Thomas, & Farran, 2018) and later entry, and success, in STEM (Lubinski, 2010; Wai, Lubinski, & Benbow, 2009). Critically, spatial thinking predicts entry into STEM careers, controlling for verbal and mathematical intelligence (Lubinski, 2010; Wai et al., 2009).

We know of several factors that contribute to the development of child spatial ability. These factors include motor skill (Frick & Mohring, 2016; Jansen, Kellner, & Rieder, 2013), working memory (Kaufman, 2007; Lehmann, Quaiser-Pohl, & Jansen, 2014; Wang and Carr, 2020), child and parent spatial language (Pruden & Levine, 2017; Pruden, Levine, & Huttenlocher, 2011), spatial anxiety (Ramirez, Gunderson, Levine, & Beilock, 2012), and spatial play (Gold et al., 2018; Levine, Ratliff, Huttenlocher, & Cannon, 2012; Nazareth, Herrera, & Pruden, 2013).

The influence of parent characteristics beyond parental use of spatial language (Pruden et al., 2011) and parental gender stereotypes (Crowley, Callanan, Tenenbaum, & Allen, 2001) is widely overlooked despite theoretical motivation to do so. According to Relational-Developmental Systems Theory (Overton, 2014), the person-in-environment (i.e., the developing child) must be analyzed within the environment, defined as its physical aspects (i.e., physical aspects of home environment), interpersonal aspects (i.e., the parent) and sociocultural aspects (i.e., parental engagement, decisions or expectations). In support of these theoretical ideas, research finds parents play a contributing role in the development of their children's abilities (Taylor, Clayton, & Rowley, 2004) and that the home environment is the most important setting, outside of school, in shaping children's academic motivation/achievement (Wang & Degol, 2013). Despite research showing the importance of parents and the structure of the home environment on children's development, little is known about how parent-specific characteristics and the home environment are related to child spatial ability. We fill this gap by examining the role that mother spatial ability and the home spatial environment play in explaining individual differences in *two* types of spatial ability in young children.

Two types of spatial ability: Intrinsic and extrinsic

Recent evidence has emerged supporting a two-factor typology for how we conceptualize spatial ability: intrinsic and extrinsic spatial thinking (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006; Mix, Hambrick, Satyam, Burgoyne, & Levine, 2018). Using confirmatory factor analysis, Mix and colleagues (2018) found evidence in support of the intrinsic/extrinsic distinction, but not for a distinction between static/dynamic spatial tasks. We adopt this intrinsic/extrinsic distinction and test whether mother intrinsic and extrinsic spatial ability relates directly or indirectly to child intrinsic and extrinsic spatial ability.

Intrinsic spatial thinking involves the relations within an object or between an object's constituent parts (Mix et al., 2018; Newcombe & Shipley, 2015). This type of spatial thinking encompasses the manipulation of shapes and objects by way of mental transformation and rotation (Hegarty et al., 2006). Several characteristics of a single object can be studied, including, the arrangement of it parts, orientation, and size (Uttal et al., 2013). Mental rotation and transformation tasks are commonly used to assess this ability. Extrinsic spatial thinking involves the relations between two or more objects or between an object and its environment (Mix et al., 2018; Newcombe & Shipley, 2015). Extrinsic spatial thinking is useful in tasks that require navigating new environments or considering where objects are from different perspectives or relative to landmarks (Atit, Uttal, & Stieff, 2020). Navigation tasks, perspective-taking tasks, proportional reasoning tasks, and spatial scaling tasks are used to assess this ability. Research examining relations between spatial thinking and STEM learning have largely emphasized intrinsic spatial thinking. The relation between extrinsic spatial thinking and STEM learning has been largely neglected. However, recent research studies show support for extrinsic spatial thinking and math and science learning (Hodgkiss et al., 2018; Wong, 2017) suggesting the investigation of factors affecting individual differences in extrinsic spatial thinking may be important to identify.

Parental spatial ability: Is parent ability related to child ability?

Research finds that an individual's cognitive ability is related to their parents' cognitive ability, controlling for educational attainment and socio-economic status (Anger

& Heineck, 2010). Work in mathematics and science show evidence of intergenerational transmission of skill from parent to child (e.g., Braham & Libertus, 2017; Hart, Ganley & Purpura, 2016). Thus, it is possible that spatial ability level can be transmitted between generations from parents to children.

In the domain of spatial thinking, a significant, direct pathway between maternal intrinsic spatial ability and daughter intrinsic spatial ability has been found (Dearing et al., 2012). In this study, maternal mental rotation scores significantly predicted child's mental rotation, mental transformation, and block design scores. The finding that mothers' intrinsic spatial ability predicts daughter's intrinsic spatial ability has since been replicated in a different sample (Casey, Dearing, Dulaney, Heyman, & Springer, 2014). It is suggested that we should consider using bio-ecological approaches to spatial development in order to better understand the contributions of both genetic mechanisms and early environments to the development of spatial skills (Casey et al., 2014; Dearing et al., 2012). We extend this prior research by not only examining the relation between mother and child intrinsic spatial ability in both preschool-aged boys and girls, but by broadening this work to extrinsic spatial ability, an area of spatial research that lacks any evidence for a relation between parent and child ability.

The home spatial environment

Early play experiences with spatial toys such as puzzles, blocks, and other types of construction materials allow children to practice and improve their spatial skills, supporting the idea that spatial toys and activities found in the home spatial environment may explain individual differences in children's spatial ability (Casey et al., 2008; Jirout & Newcombe, 2015; Levine, Ratliff, Huttenlocher, & Cannon, 2012; Oostermeijer, Boonen, & Jolles, 2014; Petty & Rule, 2008; Vander Heyden, Huizinga, & Jolles, 2017). Jirout and Newcombe (2008) observed a correlation between parent-reported frequency of spatial play at home and child block design scores in a large, nationally-representative sample. A similar relation has also been found between puzzle play and children's mental transformation, another type of intrinsic spatial ability. Levine and colleagues (2012) observed parent-child dyads at home for 90 minutes at six time points between 2 and 4 years and found that children who played more frequently with puzzles performed better on mental transformation (Levine et al., 2012). Finally, block building activity interventions have yielded improvement in mental rotation task scores among kindergarten students (Casey et al., 2008).

Through retrospective studies we have also established a relation between engagement in spatial activities in childhood and adult spatial ability. Doyle and colleagues (2012) found that participants who engaged in spatial activities in their childhood, performed better on the Mental Rotation Task and the Water Level Task as adults. Nazareth and colleagues (2013) showed that the number of masculine-typed spatial activities participants had engaged with in childhood mediated sex differences in mental rotation scores. Together with the studies on children, these results suggest a role for the engagement in spatial activities and toys in early childhood in explaining individual differences in children's spatial ability. What remains unclear is how parent spatial ability and the early home spatial environment work together in developing children's spatial skills.

Parents play an important role in the selection of activities for and promotion of the home learning environment. High-quality home learning environments require that (1) parents provide access to learning and play materials that stimulate cognitive growth; and (2) parents and their children engage in these enriching, learning-related activities together (Dearing et al., 2012; Elliott, Bachman, & Henry, 2019; Taylor et al., 2004). Vygotsky's sociocultural theory, which suggests that cognitive development occurs through social interactions between a less experienced individual and a more experienced individual, echoes the sentiment that collaborative home-based, informal activities between child and parent can promote child learning (Ramani & Siegler, 2014; Vygotsky, 1978). Further, the theory of academic socialization posits that parents' attitudes and parenting practices provide the foundation for their child's school performance (Taylor et al., 2004). Thus, there is reason to believe that parents' selection of high-quality informal activities and toys for the home environment and parent-child engagement in these activities impact child learning.

Relations between parent spatial ability and home spatial environment

It is plausible that parent spatial ability will directly explain individual differences in child spatial ability, however, there also exists the possibility that parents with higher spatial ability provide more spatially-enriched environments thereby creating an *indirect* link between parent and child spatial ability (Kotsopoulos, Makosz, Zambrzycka, & Dickson, 2019). A correlation between parental spatial support at home and parent's beliefs about their own spatial abilities suggests that parent's own spatial ability may influence the promotion of the home spatial environment (Zippert & Rittle-Johnson, 2020). Theory and behavioral genetic studies suggest that a child's traits are influenced by both the genotype that the child inherits from their parents, as well as the rearing environment the child receives (Hart, Little & van Bergen, 2019; Plomin, DeFries & Loehlin, 1977). Passive genotype-environment effects appear in biologically-related families in which parents provide both genes and rearing environments for their biological children (Scarr & McCartney, 1983). For example, parents who excel at math and enjoy math are more likely to provide their children with math resources/activities at home and so their children are more likely to be skilled at math and enjoy math due to a combination of both genetic and environmental factors.

The promotion of the home spatial environment is important because informal learning activities such as play serve as opportunities for parents to provide children with new information to increase their understanding of concepts (Casey et al., 2014; Ramani & Siegler, 2014). Casey and colleagues (2014) investigated whether maternal support during joint spatial play mediated the relation between mother and daughter spatial ability. In this study, mother-daughter dyads were videotaped participating in a joint origami activity and mothers were rated on quality of assistance (the structure that the mother provided in order to enable her daughter to be successful in solving the task) andstimulation of cognitive development (the extent to which the mother used the task as a cognitive leaning opportunity for her daughter). Mothers with higher spatial ability tendedto provide higher quality interactions to facilitate their daughters' spatial learning than mothers with lower spatial ability, partially explaining the relation between maternal spatial skills and daughter spatial skills (Casey et al., 2014). Furthermore, research on parents' cognitions about school appears to influence parenting practices and selection of activities for children, which in turn influences children's scholastic achievement (Elliott & Bachman, 2018; Taylor et al., 2004). Given the sparse literature on how parent spatial ability and the home spatial environment are related to children's spatial ability and the idea that environment that parents provide should be considered in conjunction with genetic influences (Hart et al., 2019), we also assess whether mother spatial ability and child spatial ability are related *indirectly* via mother toy choice and mother-child engagement in spatial activities in the home setting, our measures of a high-quality home spatial environment.

Study aims and predictions

We will explore how mother spatial ability, both intrinsic and extrinsic, directly and indirectly, via mother intrinsic spatial toy preference and frequency of mother-child engagement in intrinsic spatial activities in the home environment, predicts children's intrinsic and extrinsic spatial ability. We have *two* specific aims: (1) examine direct relations between mother and child intrinsic and extrinsic spatial ability; and (2) examine indirect effects of home spatial environment (as measured via mother toy choice and mother-child engagement in spatial activities in the home) on the relation between mother and child intrinsic and extrinsic spatial ability. Our hypotheses related to the first aim are: (1a) mother intrinsic spatial ability will be significantly, positively-related with child intrinsic spatial ability, controlling for child gender, child age, mother education, general home environment, and child receptive vocabulary; and (1b) mother extrinsic spatial ability will be significantly, positively-related with child extrinsic spatial ability controlling for child gender, child age, mother education, general home environment, and child receptive vocabulary. These first two hypotheses are informed by literature showing established links between parent and child ability across both domain-general cognitive research (Anger & Heineck, 2010) and domain-specific math and spatial research (Braham & Libertus, 2017; Casey et al., 2014; Dearing et al., 2012). Our hypotheses related to the second aim are: (2a) the direct relation between mother intrinsic spatial ability and child intrinsic ability *will be* mediated by mother intrinsic spatial toy preference and the home intrinsic spatial environment, controlling for child gender, child age, mother education, general home environment and child receptive vocabulary; and (2b) the direct relation between mother extrinsic spatial ability and child extrinsic ability *will not* be mediated by mother intrinsic spatial toy preference and the home intrinsic spatial environment, controlling for child gender, child age, mother education, general home environment, and child receptive vocabulary. Hypothesis 2a is informed by literature showing that parents with higher spatial ability provide higher quality interactions during joint spatial play than parents with lower spatial ability (Casey et al., 2014; Ramani & Siegler, 2014) and the findings in adult literature showing that engagement in early spatial activities predicts adult mental rotation ability (Nazareth, Herrera & Pruden, 2013). Contrary to Hypothesis 2a, we do not expect the same pattern of results for extrinsic spatial ability (Hypothesis 2b) as we believe that engagement in the types of toys and spatial activities assessed in our measures, the *Intrinsic Spatial Toy Preference Task* and the *Home Intrinsic Spatial Environment Questionnaire*, are not the mechanism by which extrinsic spatial ability, such as navigation, wayfinding, understanding maps, and scaled representations develop. They serve as the primary mechanism for the development of intrinsic spatial abilities, such as mental rotation and spatial visualization as these toys and activities largely require abilities like object rotation and manipulation. For this reason, we believe that the intrinsic spatial toys and experiences measured in our *Intrinsic Spatial Toy Preference Task* and the *Home Intrinsic Spatial Environment Questionnaire* lend themselves to the development of intrinsic spatial ability but not extrinsic spatial ability. To our knowledge, there is no empirical evidence in the existing literature to suggest that exposure to the types of activities and toys (i.e., blocks, puzzles) typically measured in home spatial environment questionnaires such as the one used in the current study explain the development of, and individual differences in, extrinsic spatial abilities the way that they are predictably associated with intrinsic spatial abilities like mental rotation and spatial visualization. Recent studies suggest that the experiential explanations for the development of cognitive mapping, navigation, and other extrinsic spatial abilities are likely early/childhood wayfinding experiences, more specifically, the frequency of roaming and range that one roams in childhood (Nazareth, Weisberg, Margulis, & Newcombe, 2018; Schug, 2016; Vieites, Pruden, & Reeb-Sutherland, 2020) which we do not examine in the current study. We do believe this contrasting hypothesis is important to examine, despite its null prediction, to show specifically what early life experiences (e.g., the toys mothers select for their children; the amount of play with those toys) result in the development of *specific types* of spatial ability.

Method

Participants

A total of 165 mothers (age range = 19 to 47 years, M = 37, SD = 4.79) and their preschool-aged children (age range = 4 to 6 years, M = 5, SD = 0.82) were recruited from various online sources including social media platforms (i.e., *Twitter, Facebook*, *Instagram*), listservs (i.e., *Cognitive Development Society* listserv) and child recruitment webpages (https://childrenhelpingscience.com). A roughly equal distribution of male and female children was recruited (51% female). Child race/ethnicity was reported as follows: 52% White, 2% Black, 22% Latino, 8% Asian, 15% Multiracial, and 1% Other.

Power analysis. In order to understand the required sample size to detect our *direct effect* of mother spatial ability on child spatial ability (Aim 1), an *a-posteriori* power analysis was conducted using R package *pwr* (v3.6.0; R Core Team, 2019). We examined the literature to provide benchmark effect sizes of the direct effect between parent ability and child ability (Braham & Libertus, 2017; Casey et al., 2014; Dearing et al., 2012). Dearing and colleagues report an effect size of r = .32 (n = 127) and Casey and colleagues report an effect size of r = .16 (n = 162) for the direct relation between maternal spatial ability and daughter spatial ability, controlling for family SES. However, these studies are not directly relevant to our question of interest because they only looked within girls. To more directly address our question, we had to look beyond studies of spatial ability. We looked at literature reporting intergenerational transmission of math ability. Braham and Libertus (2017) found a correlation of r = .39 (n = 57) between parents' approximate number system (ANS) acuity and child's ANS acuity. Based on this effect size, our power analysis for direct effects suggests the n needed is 64 to achieve a power of .90.

However, the model components requiring the most power are the mediated or indirect effects, the goal of Aim 2. To properly estimate sample size, we assessed the *indirect effect* of mother spatial ability, via mother intrinsic spatial toy preference and home intrinsic spatial environment, on child spatial ability. In mediation models, the indirect effect is quantified as the product of the a path (from X □ M) and the b path (from M □ Y) in the model (Baron & Kenny, 1986; Hayes, 2017). Because the sampling distribution of a product term is not normal, the modern literature recommends assessing significance of indirect effects using bootstrap resampling methods, which can properly approximate asymmetric sampling distributions (Fritz & MacKinnon, 2010; Hayes, 2013; Hayes & Preacher, 2013). There is scant literature on the indirect effect of the home environment on intergenerational transmission of parent to child spatial and math ability. Therefore, we looked to research on intergenerational transmission between parent and child ability and the indirect effect of the home environment in another domain, reading, for an estimate of indirect effect size. Van Bergen and colleagues (2016) examined the indirect effect of home reading environment (i.e., number of books in home) on the relation between mother reading ability and child reading ability. Van Bergen et al. (2016) reported standardized relations of a = .24 and b = .36, resulting in an indirect effect of .24 * .36 = .0864. This was used as the benchmark effect size in the follow-up power simulation study, which determined the sample size needed to achieve a power of .90 to detect statistical significance for the indirect effect.

We conducted this simulation study using R statistical software. We simulated X as a standard normal variable with mean equal to zero and standard deviation equal to one. We modeled M and Y according to the equations $M = aX + e_M$ and $Y = bM + e_Y$ with the variance of the residuals scaled to ensure M and Y would be standardized variables with variances equal to unity. Note that, for convenience, we set the direct effect of X equal to zero, absent another plausible value from the literature to use in the simulation. In the simulation, we first set a target sample size. Then, we generated 1,000 simulated datasets according to our mediation model, each with sample size N. We analyzed all datasets using the *lavaan* package for latent variable analysis in R (Rosseel, 2012) with 1,000 bootstrap resamples each. We saved a dichotomous variable coded 1 if the bias-corrected bootstrap confidence interval for the indirect effect in a given dataset did not contain zero (indicating a significant result), and notated zero otherwise. The mean of this dichotomous variable indicated the proportion of significant results across the 1,000 simulated datasets, an estimate of empirical power. Using the indirect effect derived from van Bergen et al. (2016) of .0864 as a benchmark and testing various effect sizes around that boundary, we found that N = 165 produced an empirical power estimate of .902. With our proposed N = 165, we should have 90.2% power to detect an indirect effect of .0864 or higher.

Treatment of missing data. Missing data was treated using Full Information Maximum Likelihood (FIML) estimates. We searched for auxiliary variables that correlated with both the model variables of interest (e.g., *Intrinsic Spatial Toy Preference Task* and *Home Intrinsic Spatial Environment Questionnaire)* and the probability of missingness, and then used those auxiliary variables as saturated correlates (Graham, 2003). Identifying auxiliary variables that fit these criteria allow us to recover power lost from missing information and potentially decrease bias (Collins, Schafer & Kam, 2001).

Inclusion criteria. The inclusion criteria that was used to screen participants for eligibility and enrollment in the study included: (1) child must be between 4- to 6-years-old; (2) families must have access to laptop or desktop computer; (3) families must have access to internet; (4) families must be able to download the Zoom application to their computer; and (5) families must self-report as proficient in English. Families received a $50 Amazon gift card for completion of this remote study. The study has been approved by the University's Institutional Review Board (IRB#20-01310-AM01).

Procedure

Mother-child dyads that are interested in and meet the inclusion criteria for the study were asked to sign up for a time slot for a one-hour interactive Zoom video session through *SignUpGenius*. Zoom sessions were offered in the evenings so that participating mothers could arrange for care (e.g., spouse, older sibling, grandparent) for the child while the mother was completing the first part of the study.

During this interactive Zoom video session, which was video recorded, the mother was asked to read the parental consent form out loud and verbally consent to their own, as well as their child's, participation. Assent from the child was not required as the authors' IRB requires assent for children 7 years and older.

The first 30 minutes of the session were used to gather data from the participating mother. The mother completed the following tasks in a fixed order: (1) *Intrinsic Spatial Toy Preference Task*; (2) *Home Intrinsic Spatial Environment Questionnaire*; (3) *Mental Rotations Test* (Peters et al., 1995; Vandenberg & Kuse, 1978); (4) adapted *Spatial Scaling Task* (Frick & Newcombe, 2012); and (5) *Demographics Questionnaire*. Fixed order of tasks was selected to ensure that any self-report data about behavior in the home was collected before gathering mother spatial ability data, which may potentially bias self-report data. To ensure confidentiality of data gathered, the mother was provided with a Qualtrics link to complete *all* questionnaires and tasks. The experimenter remained available on the Zoom video call while the mother completed each questionnaire and task in order to provide directions, answer questions the mother had, and to confirm electronic receipt of a complete dataset for the mother. These steps allowed us to check the quality of our parent data in real time.

The last 30 minutes of the session were used to gather data from the participating child. The child completed the following tasks in a fixed order: (1) *Color Training Trials*; (2) *Picture Rotation Test* (Quaiser-Pohl, 2003); (3) adapted *Spatial Scaling Task* (Frick & Newcombe, 2012); (4) *Number Training Trials*; and (5) *Peabody Picture Vocabulary Test, Version 5* (*PPVT-5*; Dunn 2019). Fixed order of tasks was selected with *Color Training*

Trials coming before those tasks that require the participant to select their response using color, *Number Training Trials* coming before the one task requiring the participant to select their response using numerals, and the *PPVT-5* administered last as it was not a main measure of interest, but a control task. All tasks were completed live with the experimenter through the Zoom video call. At the end of the video session, mothers were debriefed as to the purpose of our study and thanked for their time.

Video sessions were recorded using the HD setting on Zoom and uploaded within 48 hours of recording to Haivision, a secure HIPPA-compliant media storage service available to the authors through their university. All child measures were coded and scored offline by trained research assistants using these stored recordings.

Mother Measures

Intrinsic Spatial Toy Preference Task

The *Intrinsic Spatial Toy Preference Task* was used to assess mothers' decisions about the types of toys they would choose for their child in the home environment. This task specifically addressed whether mothers would prefer to purchase a "highly spatial" toy when provided a choice between a "highly spatial" and "less spatial" toy. This measure served as a direct assessment of preference for highly spatial toys under the same experimental constraints for all participants. A major advantage of the forced-choice assessment is that the playing field is level—despite differences in socioeconomic means or other factors that may affect toy purchase behaviors, all mothers were given the opportunity to make a decision about the same toys.

Using a forced-choice preference task, mothers were asked to make a hypothetical decision about which toy they would prefer to buy for their child. Pictures of toys were shown to mothers. This task took between 3 to 5 minutes to complete. There were 12 trials in which the mother was asked to make a decision between two educational toys: (1) a “highly spatial” educational toy; and (2) a “less-spatial” educational toy (see Figure 2 for sample item). Instructions read, “Which of the two toys on your screen would you prefer to buy for your child?” The toys included in the task have previously been rated on a 1 (“least spatial”) to 5 (“highly spatial”) scale by spatial development experts in the field (Abad, 2018). For this task, we categorized toys rated with 4’s or 5’s as “highly spatial” (e.g., set of magnetic tiles) and pitted them against “less-spatial” educational toys that had been rated between 1 and 3 (e.g., musical instrument). Toys included in this task had also been rated by 298 undergraduate students (Abad, 2018) as gender-neutral, and appropriate for play by either boys or girls; in this pilot study no sex differences in children’s engagement with toys used for this task were found. We matched these pairings based on price and were careful to select gender-neutral toys because two factors appear to bias a parent’s decision when choosing a toy to hypothetically purchase: (1) economic and other cost considerations; and (2) gender typicality of toys. Research in consumer psychology finds that parents may be biased to spend more on toys for children of the same sex and under certain economic conditions for daughters (Nikiforidis, Durante, Redden & Griskevicius, 2017), and that the cost or price of a toy influenced parent decision-making (Al Kurdi, 2017). There is also research showing that parents are more likely to purchase gender-typed toys for their prospective children or own children (Fisher-Thompson, 1993; Fisher-Thompson, Sausa, and Wright, 1995; Weisgram & Bruun, 2018), suggesting that the gender-typing of toys may impact parent decision-making about toy choice. Thus, literature seems to point to the two factors above, as well as parent and child demographic factors, which we control for in the present study (e.g., parent and child gender, parent education), as the likely candidates for parent toy choice.

Mother ratings were scored by allocating 1 point for each “highly spatial” toy chosen, yielding a possible score of 0 to 12 points for the variable *Mother Toy Choice*.

Home Intrinsic Spatial Activities Questionnaire

The *Home Intrinsic Spatial Activities Questionnaire* was used to measure frequency of family engagement with “highly spatial” activities and toys in the home environment and serves as our Home Intrinsic Spatial Environment variable. Existing measures, like Dearing et al. (2012), ask about child frequency of play with a variety of spatial activities, but do not inquire specifically about mother-child engagement with these toys, the purpose of our measure. Mothers were asked to rate the frequency with which they co-engage in 12 “highly spatial” activities with their child in the home environment on a scale from 0 (“never”) to 5 (“daily/almost daily”). The spatial activities included in this questionnaire were connecting blocks, stacking blocks, marble runs, magnetic constructions toys, origami, jigsaw puzzles, floor puzzles, mazes, peg puzzles, stacking games, playdoh/modeling clay and train/race car building sets. All of the items included were rated as 4’s or 5’s on a spatial rating scale by spatial development experts in the field (Abad, 2018). Mothers were also asked to rate the frequency with which they co-engage in six “less spatial” activities (e.g., reading, coloring, board games, play with stuffed animals, musical instruments and play with cars) with their child in the home environment on the same scale so as to determine whether it is frequency of “highly spatial” play or play more broadly, that is driving reported effects. These items had been rated as 1’s or 2’s on the spatial rating scale by Abad (2018). The average time to complete this questionnaire was

3 to 5 minutes.

The variable *Home Intrinsic Spatial Environment* was calculated by taking the mean frequency of engagement across all 12 “highly spatial” activities. A measure of *General Home Environment* was calculated, and used as a control for frequency of mother-child engagement in activities in general, by taking the mean frequency of engagement across the six “less spatial” activities.

Intrinsic Spatial Task: Mental Rotations Test

An abbreviated version of the Revised Vandenberg and Kuse *Mental Rotations Test* (Peters et al., 1995; Vandenberg & Kuse, 1978) was used as a measure of *Mother Intrinsic Spatial Ability*. This task assesses the ability to rotate 3-D cubed objects and find two matching rotations from an array of four possible items. The first twelve items from the *Mental Rotations Test* were administered. A reduction in number of items administered was necessary to reduce participant fatigue, attrition and total study time. Mothers were asked to select the two figures that they believed were the rotated versions of a target figure. The instructions will read: “Two of these four drawings show the same object. Can you find those two?” For each item there were two incorrect figures that are mirror-images of the target and two correct items that are rotated but identical to the target. Mothers were provided with two training trials to familiarize them with the task instructions and task demands. An untimed version was administered to prevent floor effects in the sample given that adult females tend to perform worse with time constraints (Goldstein et al., 1990; Voyer, 2011; Voyer & Sullivan, 2003), and to be comparable to the children’s Picture Rotation Task which is also untimed. Published studies show that untimed versions of the Mental Rotation Task (MRT) do yield variability in adult scores with no ceiling or floor effects (Alvarez-Vargas, Abad & Pruden, 2020; Titze, Heil & Jansen, 2008; Voyer & Doyle, 2010). This is the case even for abbreviated versions of the MRT (Casey, Dearing, Delaney, Heyman & Springer, 2014; Dearing et al., 2012). Thus, we feel confident that we will see sufficient variability in mother MRT scores. Mothers only received a point if both of their selections are accurate for each trial. This resulted in a range of scores from 0 to 12 for *Mother Intrinsic Spatial Ability*.

Extrinsic Spatial Task: Spatial Scaling Task

The *Spatial Scaling Task* originally created by Frick and Newcombe (2012) was adapted to be used with adults as a measure of *Mother Extrinsic Spatial Thinking*. This task assessed spatial scaling, a skill necessary for reading and drawing maps and navigation more generally. In the original version, participants are shown the location of an egg (target) on a small map and asked to point to the corresponding location of the egg (target) on a large, scaled-up version of the same map. No possible answer choices are given, rather the participant is simply asked to point to or place a pointer on where they think the egg is located. The millimeter deviation of the participant's estimate of location from the correct location is calculated.

To make this task remote-friendly and developmentally-appropriate for adults, we modified it to: (a) make it multiple-choice format with four possible responses; and (b) created only one correct location, and three foils on large, scaled-up maps of which two response options were close to the target location (within 90 degrees of the target), and one response option was not close to the target location (more than 90 degrees away from the target). Thus, two response options are close to the target location (in the same quadrant as the target) and one response option is further away from the target (in one of the other three quadrants). In this adapted version, mothers were shown the location of an egg (target) on a small map and asked to select the one corresponding location of the egg (target) from four large maps. The small map and four large maps corresponded according to a 1:4 scaling factor.

The instructions read, "*The egg is in the same location in the target map as it is in the response map. Which of these four maps show the egg in the correct location?"* The participant was able to see the small map and the four response choices (large maps) on their screen (see Figure 3 for sample item). The adapted *Spatial Scaling Task* consisted of 12 trials and 2 training trials using a 1:1 scaling factor and the average time for completion was 10 minutes. The variable *Mother Extrinsic Spatial Ability* was calculated based on the number of items answered correctly with possible scores ranging from 0 to 12.

This adapted *Spatial Scaling Task* was piloted using 29 undergraduate students to assess appropriateness with an adult population and whether it yields sufficient variability. Results revealed that the average score on this 12-item task was 8.76 (SD = 2.49; *Range* 3-12). The average of 8.76 is greater than chance responding, based on the binomial test ($p < 0.002$). Thus, we are confident that this adapted *Spatial Scaling Task* is appropriate for use with adults and will yield variability when administered to mothers.

Demographic Information Questionnaire.

The *Demographic Information Questionnaire* consisted of questions about child age, child gender, child race/ethnicity, child handedness, mother education, mothers' age, type of device used to complete the study, and computer screen size. Data collected from the *Demographic Information Questionnaire* was used to control for child gender, child age, and mother education. Mother education was included as a control variable since research shows that families with fewer resources likely have less stimulating home learning environments in general (Bradley, Corwyn, McAdoo, & Garcia Coll, 2001; Dearing et al., 2012; Hart et al., 2016). Information about device used (type and screen size) was gathered and examined to ensure that spatial scaling scores are not confounded by screen size. This information served as a data quality check to ensure our data are not explained by potential confounding variables (i.e., device type, screen size) or variables not of interest in this study known to explain individual differences in children's spatial ability (i.e., child gender, child age, mother education; Bradley et al., 2001; Dearing et al., 2012). *Child gender,* a categorical variable, was dummy coded as 1 = female and 2 = male. *Child age* was reported as a continuous variable in months. *Mother education,* a categorical variable, was dummy coded as 1 = some elementary school, 2 = some high school, 3 = high school graduate/GED, 4 = some college, no degree, 5 = Associates degree (AA, AS), 6 = Bachelor's degree (BA, BS), 7 = Master's degree (MA, MS, Med, MSW, MBA), 8 = Professional degree (Ph.D., MD, JD).

Child Measures

Color Training Trials

Color Training Trials were used to ensure that data gathered from the *Picture Rotation Task* and child-friendly, adapted *Spatial Scaling Task*, which were modified for remote administration, are valid. These tasks were modified by including a color background behind each potential answer choice, thus requiring the child to respond with a color name when selecting their answer choice. Across three *Color Training Trials*, children were asked to identify the colors blue, yellow, and purple. The color appeared on the screen and the experimenter asked, *"What color is this?"* The child had to respond with

100% accuracy to advance to other measures, otherwise testing was discontinued. The colors selected for this study (blue, yellow, and purple) were carefully chosen because they avoid the colors red and green in case a child has red-green color blindness and are colors typically acquired before four years of age (Pitchford & Mullen, 2002).

Intrinsic Spatial Task: Picture Rotation Task

The *Picture Rotation Task* (Quaiser-Pohl, 2003) was used as a measure of *Child Intrinsic Spatial Ability*. The *Picture Rotation Task* assesses children's ability to mentally rotate 3-D pictures of humans and animals and is reported to have high reliability (Cronbach's alpha = .751) and validity with other measures of mental rotation (r = .727 with letter rotation test) in children aged 4- to 6-years.

Traditionally administered as a pointing task, we modified it for remote administration by placing color backgrounds behind test items so that children can indicate their selection by simply verbally responding with the color. In this task, the experimenter showed via screenshare one target stimulus (e.g., tiger at 0º) and three test items, one of which was the identical stimulus but just rotated (e.g., tiger at 315º; rotations range from 45 º -315 º) and two of which were rotated mirror images of target stimulus that can never match the target stimulus. The target stimulus was presented on the left side of the screen and a line separated it from the three test items displayed on the right side of the screen. The experimenter said, *"Here you see the picture of a tiger. One of these tigers here* (using the mouse curser, experimenter pointed to the pictures to the right of the line) *is the same as the first one* (using the mouse curser, experimenter pointed to the target stimulus). *Can you tell me which one is the same: blue, yellow, or purple?"* The participant verbally indicated their response by saying "blue", "yellow", or "purple". The order of the "blue", “yellow”, and “purple” response options was counterbalanced across trials. A total of 16 test trials were administered, with an additional two training trials at the beginning of this task to familiarize the child with task instructions. Children were provided feedback after the two training trials, but no feedback was provided for the 16 test trials. Trials were administered sequentially such that only one trial was presented on the screenshare at a time. This task took approximately 5 to 10 minutes to administer. The variable *Child Intrinsic Spatial Ability* was calculated by summing the number of correct answers across the 16 trials, for a potential range of scores of 0 to 16.

Extrinsic Spatial Task: Spatial Scaling Task

A child-friendly, adapted version of the *Spatial Scaling Task,* originally developed by Frick and Newcombe (2012), was used as our measure of *Child Extrinsic Spatial Ability*. Like the adult version, this task measures one’s ability to locate objects on a 2-D spatial layout using information from a scaled representation or scaled map. Like the adult version, we adapted this task to make it remote-friendly and developmentally-appropriate for young children by modifying it to: (a) make it multiple-choice format with *three* possible responses, each with a different color background around it; and (b) use only one correct location, and two foils on large, scaled-up maps of which one response option was close to the target location (within 90 degrees of the target), and one response option was not close to the target location (more than 90 degrees away from the target). In this adapted version, children were shown the location of an egg (target) on a small map and asked to select the one corresponding location of the egg (target) from three large maps. The small map and three large maps corresponded according to a 1:4 scaling factor.

The experimenter read the child a story about Farmer Fred and asked the participant to help Farmer Fred locate the hidden eggs (target). Participants were then shown, via screenshare, the location of an egg (target) on a small map and asked to select the corresponding location of the egg (target) from three large maps. The experimenter asked, *"The egg is in the same spot in the small map as it is in the large map. Which of these large maps show the egg in the correct spot? Is it the blue map, yellow map or purple map?"* The participant verbally indicated their response by saying "blue", "yellow", or "purple". The participant was able to see the small map and the four response choices (large maps) on their screen (see Figure 4 for sample item). The adapted child-friendly *Spatial Scaling Task* consisted of 12 trials and 2 training trials using a 1:1 scaling factor and the average time for completion was 5 minutes. The variable *Child Extrinsic Spatial Thinking* was calculated based on the number of items answered correctly with possible scores ranging from 0 to 12.

Number Training Trials

Number Training Trials were used to ensure that data gathered from the *Peabody Picture Vocabulary Test, Version 5* (Dunn, 2019), which was administered remotely and required a verbal response, were valid. Across four *Number Training Trials,* children were asked to identify the numerals, 1, 2, 3 and 4. The numeral appeared on the screen and the experimenter asked, *"What number is this?"* The child must respond with 100% accuracy to advance to the *PPVT-5,* otherwise testing was discontinued.

Peabody Picture Vocabulary Test, Version 5

The *PPVT-5* (Dunn, 2019) is a standardized measure used to measure the variable we call, *Child Receptive Vocabulary*. We used the *PPVT-5* scores as a covariate in all analyses to ensure our results are not explained by general intelligence. The *PPVT-5* was administered via Pearson's Q-global whereby the digital stimulus book was shown on the participant's screen. The participant selected the appropriate image (out of four possibilities) that matches the spoken word. The participant verbally responded with the selection of image using the numerals, "1", "2", "3", or "4". The participant was administered two training items to ensure understanding of the test. Upon successful completion of these trials, a basal receptive vocabulary score was established when a child answered three consecutive items correctly. For children between the ages of 4:0 and 4:11, the test began with item 12. For children between the ages of 5:0 and 5:11, the test began with item 26. For children between the ages of 6:0 and 6:11, the test began with item 53. The test was discontinued once the child received six consecutive incorrect answers (ceiling). Scores were generated by *PPVT-5* Q-global using basal and ceiling scores. This task took approximately 15-20 minutes to complete, although completion time varied depending child proficiency.

Results

We ran mediation models in the structural equational model (SEM) framework using Mplus version 8 (Muthen & Muthen, 2017) and tested both indirect effects using bias-corrected bootstrap methods (1,000 iterations), as currently recommended by quantitative methodologists (Fritz & MacKinnon, 2010; Hayes & Preacher, 2013). The models were saturated and thus obviated assessment of fit. However, both direct and indirect effects are of interest. Thus, we examined the reliability of each path weight against the standard error of the estimate, calculated using the bias-corrected bootstrap. Confidence intervals for each path weight were calculated from bias-corrected bootstrap standard errors.

Descriptive Statistics

All measures administered to the mothers were complete, however, there was a moderate amount of missing child data due to child failure of training trials or fatigue. There was 44% missingness for the Peabody Picture Vocabulary Test, 34% missingness for the Picture Rotation Test, and 18% missingness for the Child Spatial Scaling Test. We used full information maximum likelihood estimation (FIML) to adjust for missing data. Descriptive statistics for each observed variable, including means, standard deviations, minimum and maximum values were reported in Table 1. These descriptive statistics were used as a way to check the quality of data, ensure that no measures showed floor or ceiling effects, and check that there was sufficient variability in each measure.

Model 1

We estimated the hypothesized structural equation model (SEM) to explore direct and indirect pathways between mothers' intrinsic spatial ability and child's intrinsic spatial ability. See Figure 5 for model. Two potential mediators, mother toy choice and home intrinsic spatial environment, were included in the model. Although not depicted in our figure for clarity, five covariates (child age, child gender, mother education, general home environment, and child receptive vocabulary) were also included in this model. An acceptable goodness of model fit was indicated for the structural model (i.e., null χ^2 and RMSEA values).

Contrary to our predictions, we did not find a direct relation between mother intrinsic spatial ability and child intrinsic spatial ability ($p = 0.38$). Further, there were no significant indirect effects via mother toy choice ($p = 0.37$) and home intrinsic spatial environment ($p = 0.86$). Although not hypothesized and not a variable of interest, child age significantly predicted child intrinsic spatial ability (b = 1.32, p <0.05) suggesting that children perform better on the *Picture Rotation Test* as they age. Output from analyses are reported in Table 2.

Model 2

We estimated the hypothesized structural equation model (SEM) to examine direct and indirect pathways between mothers' extrinsic spatial ability and child's extrinsic spatial ability. See Figure 6 for model. Two potential mediators, mother toy choice and home intrinsic spatial environment, were included in the model. Although not depicted in our figure for clarity, five covariates (child age, child gender, mother education, general home environment, and child receptive vocabulary) were also included in this model. An acceptable goodness of model fit was indicated for the structural model (i.e., null χ^2 and RMSEA values). Contrary to our predictions, we did not find a direct relation between mother extrinsic spatial ability and child extrinsic spatial ability (p = 0.43). Further, there were no significant indirect effects via mother toy choice (p = 0.83) and home intrinsic spatial environment (p = 0.52). Output from analyses are reported in Table 3.

Discussion

The present study aimed to add to the knowledge on relations between mother spatial ability, the early home spatial environment, and children's development of intrinsic and extrinsic spatial abilities. This work extends previous work as it includes both girls and boys, not just girls, and includes both intrinsic and extrinsic spatial abilities, not just intrinsic spatial abilities. Contrary to our hypothesis, mother spatial abilities (both intrinsic and extrinsic) were not significantly related to child spatial abilities, when controlling for child age, child gender, mother education, general home environment, and child receptive vocabulary. Additionally, the relation between mother and child spatial ability were not mediated by the two early home spatial environment variables (mother toy choice and home intrinsic spatial environment) measured in this study.

Aim 1

Surprisingly, mothers' intrinsic spatial ability was not related to child's intrinsic spatial ability and mothers' extrinsic spatial ability was not related to child's extrinsic spatial ability. From these findings, we cannot infer that there is a connection between mother and child spatial abilities. These findings do not replicate previous findings that mother intrinsic spatial skills predict daughter intrinsic spatial skills (Dearing et al., 2012). However, in this study, we examine mother spatial abilities in relation to both boys' and girls' spatial abilities, not just girls. It is possible that the findings that mother and daughter spatial skills are related (Dearing et al., 2012) is unique to girls and does not extend to both girls and boys. To our knowledge, this is one of the first studies to examine mother spatial ability in relation to child (non-gender specific) ability so more research is needed to determine whether there is a significant association between mother and child intrinsic and extrinsic spatial ability.

Aim 2

Results do not show any relation between mothers' intrinsic and extrinsic spatial ability and their toy choices and frequency of engagement in joint spatial play. Mother toy choice, as measured by the *Intrinsic Spatial Toy Preference Task*, was included in our analyses to explore whether mothers' internal bias toward specific types of toys would affect children's intrinsic and extrinsic spatial abilities. We did not find any evidence that mother toy choice was related to either children intrinsic or extrinsic spatial ability.

Although the *Intrinsic Spatial Toy Preference Task* was designed to assess mothers' preferences for different types of educational toys in a hypothetical context unaffected by socioeconomic constraints, it is possible that mothers inaccurately reported their choices, overreporting their preference for spatial toys, because of social desirability bias. Further, mothers could have chosen toys that they knew their child would like instead of only taking into account their own opinions and preferences.

Contrary to our prediction, but in line with recent research findings (Casey et al., 2014; Dearing et al., 2012), we did not find that home-based spatial play predicted child intrinsic spatial ability. Given this null result, it is possible that early home spatial environment is not captured accurately in our study. We defined the intrinsic home spatial environment as joint engagement between mother and child in spatial activities in the home setting, but perhaps exposure to spatial activities are not enough to improve spatial abilities, but rather, other elements of the early home spatial environment not measured in this present study such as spatial language used in the home and mothers' supportive interactions during joint spatial play (Casey et al., 2014; Dearing et al., 2012). Going forward, this line of research should move away from measuring the quantity of mother-child spatial play and instead toward measuring the quality of mother-child spatial play through observational and qualitative studies. As we predicted, home-based spatial play was not a predictor of child extrinsic spatial ability. We did not expect to find that engagement with the toys included in our *Home Intrinsic Spatial Environment Questionnaire* (i.e., blocks, puzzles) would lend themselves to the development of children's extrinsic spatial abilities. Experiences such as wayfinding and roaming, which are not included in the questionnaire, may be more predictive of children's extrinsic spatial abilities and should be further investigated in future studies (Nazareth et al., 2018; Schug, 2016; Vieites et al., 2020).

Limitations

This present study has a few limitations worth discussing. The greatest limitation is that fathers are omitted from this study resulting in an incomplete view of the early home spatial environment. It is possible that in some cases, the father, not the mother, is the one engaging their child in spatial activities or that fathers make a unique contribution above and beyond that of the mother. The father's contribution to the child's early home spatial environment, in addition to the mother's, should be explored in future studies. The second limitation is that mothers may have inaccurately recalled the amount of spatial play in the home or over reported their interest in spatial toys and the frequency in which they engage their child in home-based spatial play due to social desirability bias. The observation of naturalistic play in the household may be a better way to construct an accurate portrayal of the home.

A third limitation is that our *Home Intrinsic Spatial Activities Questionnaire* was not comprehensive as it only inquired about mother-child frequency of engagement in spatial activities in the home setting and did not inquire about access to toys (i.e., which toys have been purchased and are available to children at home). Moreover, the questionnaire only included twelve specific spatial toys, which is not an exhaustive list. Further, this measure does not take into account spatial language (Pruden et al., 2011) and quality of mother support and guidance while engaging in spatial activities (Casey et al., 2014). Additionally, it is possible that there was variability in the way that mothers interpreted the prompting question. For instance, some mothers may define "playing with" as supervising their child or sitting next to their child as they engage with a spatial toy whereas some mothers may define "playing with" as being actively engaged, providing support, teaching concepts while the child engages with a spatial toy as "playing with". Again, observational or qualitative measures can potentially be a more accurate portrayal of what happens in the home setting than a frequency count. Lastly, our questionnaire did not differentiate between spatial play alone versus spatial play with peers versus spatial play with a parent or an adult. It would be interesting to further probe whether spatial play alone versus spatial play with peers versus spatial play with a parent or an adult make unique contributions to children's spatial abilities.

Conclusion

In summary, we did not find that mothers' spatial ability, mothers' choices about toys, and joint spatial play predict children's spatial abilities. These are surprising findings that contradicted our hypotheses but replicate recent findings that frequency of spatial play does not predict children's spatial abilities (Casey et al., 2014; Dearing et al., 2012) so future studies should consider alternate conceptualizations of the home spatial environment such as the amount of spatial language used in the home or the quality of parent-child interactions surrounding spatial activities. It is possible that mother spatial ability may be related to the quality of the home spatial environment, which is not measured in the present study, rather than the number of spatial experiences in the home setting. Further, other factors that were not measured in this study (e.g., father characteristics such as ability, interest, and anxiety, child characteristics such as ability, interest, and anxiety) may drive the promotion of the early home spatial environment. Moreover, the early home spatial environment can also be predicting a child characteristic besides spatial ability such as children’s interest in STEM. We hope that this study serves as a starting point for future research that will help us better understand how cultural factors shape children’s spatial development.

IV. Mothers' Interest and Anxiety in Relation to the Early Home Spatial Environment

Spatial skills such as manipulating objects and navigating through spaces are important for the completion of everyday tasks (e.g., interpreting charts and graphs, driving without a GPS) and for success in Science, Technology, Engineering, and Mathematics (STEM). Spatial skills are related to children's math (Casey, Dearing, Dulaney, Heyman, & Springer, 2014; Casey et al., 2015; Georges, Cornu, & Schiltz, 2019; Gilligan, Flouri, & Farran, 2017; Gilligan, Hodgkiss, Thomas, & Farran, 2018; Gunderson, Ramirez, Beilock, & Levine, 2012; Jirout, Holmes, Ramsook, & Newcombe, 2018; Rittle-Johnson, Zippert, & Boice, 2019; Verdine et al., 2014b; for review see Mix, 2019) and science outcomes (Ganley, Vasilyeva, & Dulaney, 2014; Hodgkiss, Gilligan, Tolmie, Thomas & Farran, 2018). Moreover, longitudinal studies show that spatial skills in childhood and adolescence predict individuals' entry and success in STEM careers in adulthood (Lubinski, 2010; Wai, Lubinski, & Benbow, 2009). These research studies showing the link between spatial skills and STEM outcomes highlight the importance of understanding spatial development. The question remains, *how* can we support the development of children's spatial skills?

Since spatial thinking is not formally taught in school settings and children spend much of their time outside of school (Dearing & Tang, 2010; Kluczniok, Lehrl, Kuger, & Rossbach, 2013), providing children with fun and developmentally appropriate opportunities to engage in spatial activities at home is a potential avenue to improve spatial performance in children (Verdine et al., 2014a). There is great variability in the quantity and quality of parents' support for spatial thinking (Pochinki, Reis, Casasola, Oakes, & LoBue, 2021) and that is partly due to the influence of parent characteristics on the home spatial environment. In other words, parent characteristics determine whether parents engage in parenting practices that support or hinder their children's spatial development. The present study aims to investigate whether mothers' characteristics, specifically, mothers' spatial anxiety and interest in STEM are related to the home spatial environment that they provide for their children. Although there are numerous ways to quantify the home spatial environment, in this paper, we will refer to the home spatial environment as the frequency of joint participation in learning activities that promote spatial thinking (e.g., puzzle play, block play) between mother and child in the home setting.

Is the Home Environment Related to Children's Spatial Ability?

There is substantial evidence that shows that the home numeracy environment that parents provide (e.g., activities that emphasize numeracy such as counting, playing card/board games, and cooking) is related to children's current and future math skills (Benavides-Varela et al., 2016; Cheung, Dulay, & McBride, 2020; LeFevre et al., 2009; Ramani, Rowe, Eason, & Leech, 2015). However, much less is known about the role that parents play in non-numeracy domains of math such as spatial thinking (Purpura et al., 2020; Zippert, Douglas, Smith, & Rittle-Johnson, 2020; Zippert & Rittle-Johnson, 2020). Research has shown that certain play experiences including block, puzzle, and engineering play allow children to practice and improve their spatial skills and thus are important contributors to spatial development (Gold, Elicker, Kellerman, Christ, Mishra, & Howe, 2021; Newcombe, 2010; Newman, Hansen, & Gutierrez, 2016; Golinkoff, Hirsh-Pasek, & Newcombe, 2014a). Gold and colleagues (2021) found that engineering play was positively correlated with preschool children's rotation/translation skills. Similarly, a five-week intervention revealed that 8-year-old children who played with blocks showed significant gains in mental rotation performance compared to their peers who played with board games

(Newman et al., 2016). When examining spatial play in the context of the home environment, Jirout and Newcombe (2015) found that parent-child spatial play, but not other types of joint play, was related to children's block design in a nationally representative sample of 847 four- to seven-year-old children. In an observational study, Levine and colleagues (2012) found that children who were observed playing with puzzles at home more frequently performed better on the child spatial transformation task than children who did not engage in puzzle play at home (Levine et al., 2012). It is important to note that some research studies have not found a significant association between parent report of spatial activities and children's spatial ability, however in these studies mothers were asked to report the frequency of engagement in which their daughters participated in spatial activities in general (independently or with others), and did not specifically ask about the spatial activities that the mother and daughter engaged in together (Casey et al., 2014; Dearing et al., 2012). It is possible that exposure to spatial experiences are not enough to foster spatial skills and that the added element of mother support and guidance while engaging in these activities are necessary to influence spatial development (Casey et al., 2014).

Boriello and Liben (2018) have shown that it is possible to increase mothers' guidance during spatial play. In their study, mothers in the experimental group were given a definition of spatial thinking, an explanation of the value of spatial skills, and examples of ways to increase and enhance spatial guidance during play. This resulted in mothers in the experimental group providing their child with more spatial language and guidance during a subsequent block play session than mothers in the control group (Borriello & Liben, 2018). Together, emerging research showing that spatial activities in the home setting are associated with children's performance on spatial tasks and evidence showing that mothers' promotion of the home spatial environment is malleable suggest that the home spatial environment can be a target for intervention. Specifically, stimulating parents to engage in more spatial play with their children may lead to better spatial skills in children.

In order to design effective trainings, workshops, and interventions that encourage parents to increase the number of play-based spatial experiences provided at home, we first need to understand parents' current practices and what influences them. Aside from socioeconomic status (Dearing et al., 2012, Gold et al., 2021, Verdine et al., 2014) and parents own spatial ability (Casey et al., 2014; Dearing et al., 2012; Zippert & Rittle-Johnson, 2020), little is known about how parent characteristics influence the home spatial environment. There is reason to believe that parents attitudes regarding spatial thinking could be related to parents' provision of, and engagement in, spatial activities in the home setting. This study addresses the gap in the literature by examining whether mothers' attitudes and emotions towards spatial thinking (e.g., spatial anxiety, interest in STEM) are related to the frequency in which they engage in spatial activities with their children within the home environment.

Parents and the Home Spatial Environment

Parents play an important role in their young children's home-based STEM learning experiences. The theory of academic socialization posits that parents' attitudes and practices provide the foundation for their children's academic performance (Taylor, Clayton, & Bowley, 2004). Further, Vygotsky's sociocultural theory proposes that cognitive development occurs through social interactions between a less experienced individual (child) and a more experienced individual (parent) which suggests that collaborative home-based activities between child and parent can promote child learning (Ramani & Siegler, 2014; Vygotsky, 1978). Guided play, where children engage in games and activities with feedback and guidance from adults, has been shown to be essential for the development of academic skills because it allows adults to set up learning opportunities for the child and support the child's learning by asking questions and giving constructive feedback (Hirsh-Pasek & Golinkoff, 2008; Weisberg, Hirsh-Pasek, & Golinkoff, 2013; Weisberg, Kittredge, Hirsh-Pasek, Golinkoff, & Klahr, 2015).

Similarly, parent-child participation in spatial activities provides excellent opportunities for parents to scaffold their children's spatial skills through the use of gestures, labels, and spatial language, and by pointing out spatial relations, asking questions, and giving feedback (Dearing & Tang, 2010; Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, & Lam, 2011; Szechter & Liben, 2004; Simpkins, Davis-Kean, & Eccles, 2005; Vygotsky, 1978). For example, a spatial scaling game that was meant to be entertaining but also included feedback from an experimenter yielded improvement in five to eight-year-old children's spatial scaling skills (Jirout, Holmes, Ramsook, & Newcombe, 2018). This shows that games and informal learning activities can be an effective way to improve children's spatial skills when there is an adult present and actively interacting with the child (Verdine et al., 2014a).

Despite theoretical reasoning (Ramani & Siegler, 2014; Taylor et al., 2004; Vygotsky, 1978) and empirical evidence (Jirout & Newcombe, 2015; Levine et al., 2012) suggesting that parents and the home environment can support children's early spatial development, few research studies have examined which, and how, parents' characteristics contribute to variability in the home spatial learning environment. Since parental attitudes play a part in shaping children's early STEM learning experiences by determining the amount and quality of play opportunities available to their children in home settings (Grob, Schlesinger, Pace, Golinkoff, & Hirsh-Pasek, 2017), parental spatial anxiety and interest in STEM are two potential contributors to the home spatial learning environment that should be investigated.

Parent Spatial Anxiety

Spatial anxiety refers to feelings of worry and discomfort provoked by the idea of completing spatial-related tasks (Lauer, Esposito, & Bauer, 2018; Lawton, 1994; Malanchini et al., 2017; Ramirez et al., 2012). Spatial anxiety can be divided into two types; small-scale spatial anxiety which can be experienced in situations that require manipulating objects (e.g., solving a puzzle, building an object such as a dresser using an instruction booklet) and large-scale spatial anxiety which arises in situations that require navigational skills (e.g., navigating in a new city, finding your way home without GPS; Lawton, 1994; Malanchini et al., 2017; Ramirez et al., 2012.) Unsurprisingly, spatial anxiety is inversely related to spatial ability (Malanchini et al., 2017). For example, large-scale spatial anxiety has been correlated with the reduced use of effective navigational strategies in adults (Lawton, 1994; Vieites, Pruden, & Reeb-Sutherland, 2020) and numberof navigation errors made on a navigation task (Hund & Minarik, 2006). Further, total spatial anxiety (both small-scale and large-scale) is correlated with lower mental rotation task scores in young children (Ramirez et al., 2012). Interestingly, parents with high mathanxiety engage their children in math activities less frequently (Berkowitz, 2018). Similarly, teachers with high spatial anxiety can negatively affect their students' spatial learning. In one study, teachers' large-scale spatial anxiety significantly predicted students' end-of-year mental rotation scores (Gunderson, Ramirez, Beilock, & Levine, 2013). Gunderson and colleagues (2013) speculated that this relation was due in part to spatially anxious teachers avoiding spatial activities in the classroom, since spatial thinking is not a standalone subject and therefore not required.

It is plausible that if teachers' spatial anxiety can impact their students' spatial ability, the same is true for parents. It is hypothesized that parents' spatial anxiety can affect children's home spatial environment in two ways. The first is that parents with highlevels of spatial anxiety may avoid spatial activities, engaging in little to no spatial activities in the home setting because spatial activities induce feelings of discomfort and nervousness. For instance, in the similar domain of mathematics, researchers have found that parents with higher levels of math anxiety engage in math activities at home less frequently than parents with low levels of math anxiety (Elliott, Bachman, & Henry, 2020). Similarly, parents of fifth grade children with higher math anxiety also reported less home-based math involvement (i.e., providing math learning materials, reviewing homework) than parents without math anxiety (Kiss & Vukovic, 2021) and parents' (both mothers andfathers) math anxiety was negatively correlated with advanced numeracy practices in the home. Additionally, mothers' math anxiety indirectly influenced children's numeracy performance via advanced numeracy practices in the home (Del Rio, Susperreguy, Strasser, & Salinas, 2017). The second is that when they do engage in spatial activities with their children, these interactions may be negative and stressful which could hinder, rather than promote, children's spatial learning. For example, highly-math-anxious parents of first to sixth grade students reported significantly more negative emotions while helping their children with math homework than less-math-anxious parents (DiStefano, O'Brien, Storozuk, Ramirez, & Maloney, 2020). More work is needed to determine whether these relations between parental spatial anxiety and the promotion of the home spatial environment are similar to the findings that parental math anxiety negatively affects the quantity and quality of early math experiences in the home setting.

Parent Interest in STEM

When parents show interest in a particular subject or domain, they tend to provide a support system at home that fosters their children's interest in that domain (Frenzel et al., 2010). For example, parents who are interested in math may purchase games and activities that foster math learning for their children (Jacob & Bleeker, 2004). Contrarily, parents who are not interested in math may purchase few or no math games for their children and encourage their children to play with these games less often due to their lack of interest. Thus, we can hypothesize that parents who are interested in STEM may choose to purchase more spatial toys and activities for their children and dedicate more time to joint spatial play at home than parents who are not interested in STEM.

To our knowledge, no research studies have investigated parents' interest in STEM in relation to the home spatial environment, but parents' interest in STEM has been found to be related to parent-child engagement in math and science activities (Cheung, Dulay, & McBride, 2020; Junge, Schmerse, Lankes, Castensen, & Steffensky, 2021). Parents' interest in math, which was measured by the frequency in which they engaged in mathematical activities on their own, was correlated with the frequency in which they engaged in home numeracy activities with their children at home (Cheung et al., 2020). Similarly, it has been found that parents' interest in science (e.g., interest in reading and learning about science) predicted frequency of engagement in science-related activities between parents and their 5-year-old children, which in turn, predicted children's science knowledge (Junge et al., 2021). These studies provide evidence that parents with high interest in math and science may be more intrinsically motivated to engage their children in math and science activities at home and we believe that this pattern of findings will be similar for engagement in spatial activities.

The Present Study

Parents choices about the toys they purchase and the amount of time they choose to spend on certain activities are influenced by some of their own characteristics. This present study aims to examine whether two specific characteristics (mothers' spatial anxiety and mothers' interest in STEM) predict the home spatial environment that these mothers provide to their 4- to 6-year-old children. In contrast to previous studies, this study does not ask mothers to report the frequency in which their child engages in an activity, but rather, the frequency in which they engage in a spatial activity *with* their child. Our specific research questions are as follows: (1) Is mothers' spatial anxiety related to frequency of mother-child spatial play in the home setting when controlling for mothers' education? (2) Is mothers' interest in STEM related to frequency of mother-child spatial play in the home setting when controlling for mothers' education? We predict that mothers' spatial anxiety will have an inverse relation with frequency of mother-child spatial play, so the higher the spatial anxiety level, the less frequent mothers engage their child spatial play since these activities could potentially provoke stress and negative emotions for the parents (DiStefano et al., 2020). Additionally, we predict that mothers' interest in STEM will be positively related to the amount of spatial play given that parents engage their children in activities that match their own interests (Cheung et al., 2020; Junge et al., 2021).

Method

Participants

A total of 152 mothers of four to six-year-old children were recruited from preschools in the greater Miami area, social media platforms (e.g., Facebook, Instagram, Twitter) and Children Helping Science (www.childrenhelpingscience.com), a website used to recruit families to participate in child development research. In order to be eligible to participate in this study, the mothers had to meet the following criteria: (1) have a child between the ages of four and six that was typically-developing, (2) have a laptop or desktop computer with access to the internet and Zoom, and (3) self-report as proficient in English. Participating mothers ranged between 19 and 47 years of age and were 63% Caucasian/White, 22% Hispanic/Latino, 11% Asian, 1% African American/Black, and 3% Multiracial or “other”. Most mothers in this sample had earned a college degree; 1% some high school, 3% high school graduate or GED, 5% some college, no degree, 8% associate’s degree, 27% bachelor’s degree, 40% master’s degree, and 16% doctoral or professional degree. Participating mothers received a $50 Amazon e-gift card for completion of this study.

Procedure

Recruitment advertisements where shared through local preschools, Facebook, Instagram, Twitter, and Children Helping Science (https://www.childrenhelpingscience.com). Interested mothers completed a screener form using the link posted in the recruitment poster to verify that they were eligible to participate in the study. A research assistant followed up with eligible mothers to schedule a Zoom video call. During the video call, the mother read the parental consent form aloud and verbally consented to participate in the study. Mothers were administered the STEM interest questions, *Home Intrinsic Spatial Activities Questionnaire, Intrinsic Spatial Anxiety Questionnaire, State-Trait Anxiety Inventory Subscale,* and *Demographic Information Questionnaire* in a fixed order through Qualtrics. The research assistant remained on the video call while the mother completed the survey to answer any questions and ensure survey completion. On average, each video call took between thirty and forty-five minutes. Participating mothers received an electronic $50-dollar Amazon gift card via email as compensation for their participation in the study.

Measures

Home Intrinsic Spatial Activities Questionnaire

The *Home Intrinsic Spatial Activities Questionnaire* was administered to measure the frequency of mother-child engagement with spatial toys and activities in the home setting. Participating mothers were asked to rate the frequency in which they engage in twelve highly spatial activities with their child outside of school on a scale from 0 “never” to 5 “daily/almost daily”. Instructions read, “On average, how often do you do each of the following with your child outside of school?” Mothers were then presented with 12 items which showed the name of the toy or activity and three sample pictures of the toy or activity. See Figure 7 for a sample item. The following spatial activities were included in this questionnaire: connecting blocks, stacking blocks, marble runs, magnetic construction toys, origami, jigsaw puzzles, floor puzzles, peg puzzles, mazes, stacking games, playdoh/modeling clay, and train/race car building sets which were all rated as 4’s or 5’s on a spatial rating scale by experts (Abad, 2018). *Mother-Child Spatial Play* was calculated as the average frequency of the twelve items, ranging from 0 to 5. On average, participating mothers took between 3 to 5 minutes to complete this task.

STEM Interest

In order to gauge STEM interest, participants were asked to select their top three favorite classes taken in high school from a list of twelve classes. The response options included six STEM related classes (e.g., physics, pre-calculus), six non-STEM related classes (e.g., United States history, foreign language), and an "other" option in which participants were able to write in a response. Instructions read, "Select your top three favorite high school classes from the following options." The STEM interest variable was calculated in this way since research shows that interest in math and science is associated with the number of math and science courses taken in high school (Wang & Degol, 2013). Participants received a *STEM Interest* score of 0 if none of the three classes selected were STEM-related, a score of 1 if one of the three classes selected were STEM-related, a score of 2 if two of the three classes selected were STEM-related, and a score of 3 if all three classes selected were STEM-related. On average, it took less than 3 minutes for participants to make their selections.

Intrinsic Spatial Anxiety Questionnaire

Participants were asked to complete an adapted version of the Spatial Anxiety Questionnaire (Alvarez-Vargas, Abad, & Pruden, 2020) to assess their intrinsic spatial anxiety. The instructions read, "We would like for you to imagine yourself being in each of the scenarios listed below. To which degree of nervousness do you feel regarding the following scenarios?" Twelve situations associated with intrinsic/small-scale spatial anxiety (e.g., solving a 1000-piece puzzle, packing a carry-on suitcase) were presented to the participants. Participants responded according to a 4-point Likert-type scale of 0 “not at all” to 3 “severely”. *Intrinsic Spatial Anxiety* was calculated as the average score of the twelve items, ranging from 0 to 3. On average, participating mothers took between 3 to 5 minutes to complete this task. Extrinsic spatial anxiety was not measured since our *Home Intrinsic Spatial Activities Questionnaire* only asks about spatial toys that require intrinsic/small-scale spatial skills.

State-Trait Anxiety Inventory Subscale

The State-Trait Anxiety Inventory subscale (Spielberger, Gorsuch, & Lushene, 1970) was used to assess mothers’ general anxiety. General anxiety served as a control variable in our analyses being that general anxiety is highly correlated to spatial anxiety (Malanchini et al., 2017). The instructions read, “To which degree of intensity do you generally feel regarding the following statements?” Participants were ask to report the degree of intensity felt in response to twenty statements (e.g., “I feel secure”) using the following 4-point Likert scale, 0 “not at all”, 1 “somewhat”, 2 “moderately so”, and 3 “very much so”. *General Anxiety* was calculated as the average score of the twelve items; possible scores ranged from 0 to 3. On average, participating mothers took between 3 to 5 minutes to complete this task.

Demographic Information Questionnaire

The demographic information questionnaire developed by the researchers asked questions regarding child age, child gender, child race/ethnicity, mothers’ education, mothers’ age, mothers’ race/ethnicity, and undergraduate major. *Mothers’ education*, which was dummy coded as 1= some elementary school, 2 = some high school, 3 = high school graduate/GED, 4 = some college, no degree, 5 = Associate’s degree (AA, AS), 6 =

Bachelor's degree (BA, BS), 7 = Master's degree (MA, MS, Med, MSW, MBA), 8 = Professional degree (PhD, MD, JD), was used as a proxy for socioeconomic status (SES). Mothers' education was used as a covariate in our analyses given that lower SES and lower parent education are associated with less access to learning materials and learning activities in the home setting (Bradley, Corwyn, Pipes McAdoo, & Garcia Coll, 2001; Eccles, 2005; Kluczniok et al., 2013) and less involvement in home-based educational activities (Napoli, Korucu, Lin, Schmitt, & Purpura, 2021; Waanders, Mendez, & Downer, 2007). Parent education is also specifically related to the amount of engineering play (Gold et al., 2021), the amount of spatial language they use with their child (Verdine et al., 2014b), and children's spatial skills (Dearing et al., 2012; Sareh, 2020).

Results

All analyses were executed using IBM SPSS Statistics, Version 25. Table 4 presents the descriptive statistics including means, standard deviations, and minimum and maximum scores for all of the assessments in this study. As a first pass at assessing possible relations between mothers' characteristics and their promotion of the home spatial environment, correlations were calculated. Table 5 presents correlations among mothers' spatial anxiety, mothers' general anxiety, mothers' interest in STEM, mothers' education, and mother-child spatial play. The first mother characteristic of interest, mothers' intrinsic spatial anxiety, was not correlated with mother-child spatial play (r = -.11, p = .18). The second mother characteristic of interest, mothers' interest in STEM, was significantly correlated with mother-child spatial play (r = .20, p = .02).

A multiple regression analysis was conducted to investigate which factors predicted the home spatial environment (see Table 6). The results of the regression indicated that the model explained 16.5% of the variance and that the model was a significant predictor of frequency of mother-child spatial play in the home setting, $F(4,147) = 7.27$, $p < .001$. As hypothesized, mothers' interest in STEM significantly predicted joint spatial play ($\beta = .20$, $p = .01$) with mothers with more interest in STEM engaging their children with higher frequency of spatial play at home. Surprisingly, mothers' general anxiety ($\beta = -.35$, $p < .001$) but not mothers' intrinsic spatial anxiety ($p = .71$) predicted joint spatial play.

To probe the significant relation between mothers' interest in STEM and mother-child spatial play, we conducted a moderation analysis to determine whether this relation was conditional on child gender using SPSS PROCESS. The decision to explore whether child gender was a moderator stems from prior research which suggests that child gender may inform the learning opportunities that parents provide for them since there is evidence that families provide more access to science toys and books to their sons compared to their daughters (Gerde, Pikus, Lee, van Egeren, & Huber, 2021) mothers built more with their sons compared to their daughters in an observed dyadic play session (Coyle & Liben, 2020). To avoid high multicollinearity with the interaction term, the STEM interest variable was centered, and the child gender variable was dummy coded (1= female, 2 = male). Results indicated that mothers' interest in STEM ($b = .17$, $p = .03$) was associated with mother-child spatial play, such that higher levels of STEM interest were associated with higher frequency of mother-child spatial play. The effect of child gender on mother-child spatial play was not signification ($p = .34$). Further, the interaction between mothers' interest in STEM and child gender was not significantly related to mother-child spatial play, $p = .69$ (see Figure 8). Thus, we conclude that there is no moderating effect of age on the relation between mothers’ interest in STEM and mother-child spatial play.

Discussion

The present study aimed to explore whether mothers’ characteristics were related to the early home spatial environment mothers provide to their four- to six-year-old children. We specifically examined mothers’ spatial anxiety and interest in STEM in relation to frequency of mother-child spatial play in the home setting. This study is one of the first to explore whether mothers’ characteristics predict the home spatial environment they provide to their children and it adds to the knowledge on the factors that contribute to the variability in children’s early home spatial environments more broadly.

We predicted that both mothers’ spatial anxiety and interest in STEM would be related to mother-child spatial play even when accounting for mothers’ education. Surprisingly, mothers’ general anxiety, but not intrinsic spatial anxiety, was related to mother-child spatial play. This finding is inconsistent with our prediction but there are a few possible explanations for the lack of significant relation. The first is that the spatial toys that we asked about were targeted to children ages 4 to 6 so they may not elicit large amounts of intrinsic spatial anxiety since they should be very simple for an adult (e.g., stacking blocks, 24-piece puzzle). As children age and spatial activities become more complex, spatially anxious mothers may have a more difficult time engaging their children in these activities and may exhibit avoidant behaviors. Research is needed to determine whether the relation between mothers’ intrinsic spatial anxiety and mother-child participation in spatial activities changes as children grow older. Also, although we did not find that mothers’ intrinsic spatial anxiety predicted frequency of joint spatial play, it is possible that mothers’ intrinsic spatial anxiety predicts the quality rather than quantity of mother-child spatial play in the home setting, which we did not measure in this study. Observations and/or qualitative studies are necessary to provide more information about whether this speculation is true. Lastly, generally anxious mothers may avoid meaningful interactions with their children and play with them less often overall than mothers with lower levels of anxiety. Future research is necessary to determine which mechanisms explain the association between mother general anxiety and mother-child spatial play.

In line with our prediction, mother's interest in STEM related to mother-child spatial play and this relation remained even when taking into account mothers' anxiety and education. Mothers who expressed interest in more STEM courses reported engaging their children in more frequent spatial activities in the home setting compared to mothers with no or little interest in STEM courses. This finding is consistent with prior research that has showed that parents whom are interested in math engage their children in more home-based math activities (Cheung et al., 2020) and parents whom are interested in science engage their children in more home-based science activities (Junge et al., 2021). Interestingly, this relation is not moderated by child gender showing that mothers with more interest in STEM engage their children, regardless of gender, in more mother-child spatial play. These findings suggest that increasing mothers' interest in STEM may increase the amount of spatial play they engage in with both their male and female children. Thus, researchers and educators should focus on efforts that help mothers with low interest in STEM understand why spatial play experiences are important and help them create high quality home spatial environments for their children. These mothers may benefit from interventions similar to Borriello and Liben's 2018 study which introduced mothers to spatial thinking and its utility and taught mothers strategies to incorporate spatial guidance during play, but at a larger scale.

This study serves as a first look into how mother characteristics can influence children's early home spatial environments. These findings show that great interest in STEM may foster mother-child engagement in spatial activities, while high levels of general anxiety may lead to reduced mother-child engagement in spatial activities. This suggests that mothers, especially those with little or no interest in STEM and high levels of anxiety, may benefit from workshops and interventions aimed to teach mothers how to foster children's spatial skills at home through play. If training programs are organized to enhance parents' knowledge of children's spatial learning, these parents should be targeted and invited to participate.

Limitations and Future Research

It is important to note that this study had a few limitations. First, this study relied on mother report of engagement in spatial activities. These reports may be biased as mothers may have reported more joint spatial play than what happens in actuality, due to social desirability. A second concern is that we only gathered information from the mother of each child. The decision to only recruit mothers was due to the fact that mothers are typically the primary caregivers and it is difficult to recruit fathers as participants. Consequently, this study only examined how mothers' characteristics can influence the home spatial learning environment but does not take into account fathers' characteristics. Since we only collected data from mothers, our understanding of the early home spatial environment is incomplete because fathers may contribute to their children's home spatial environments as well. Building from this study, future studies should explore how fathers' characteristics influence their decisions to engage their children in spatial play.

It is also important to note that additional research is needed to determine other factors that account for variation in the promotion of the home spatial environment. In this present study we only examined two characteristics, but there are several other characteristics that may influence mother-child spatial play, such as mothers' own spatial ability or beliefs of efficacy and beliefs about the importance of spatial thinking. Future studies should examine these factors in order to determine whether they explain additional variance in our statistical model. Also, the decisions that parents make about what types of play and learning opportunities to provide at home are also informed by child characteristics aside from child gender that were not measured in this study such as child interest and spatial ability. Additionally, some parents may be driven to engage in spatial activities at home because of their child's interest instead of their own (Elliot et al., 2019).

Moreover, the *Home Intrinsic Spatial Activities Questionnaire* developed by the researchers do not take into account other aspects of the home spatial environment aside from spatial toys. Parent characteristics should also be examined in relation to spatial language (Ferrara et al., 2011; Ramani et al., 2015), and books and television shows with spatial content (Gerde et al., 2021) in the home environment. Further, spatial experiences that mothers provide outside of the home setting such as museum visits and extracurricular activities such as sports and clubs are not measured in this study. Last, future research studies should examine how the interaction between mothers' characteristics and the early home spatial environment relates to concurrent and later child spatial, math, and science outcomes. Moderation and mediation analyses are necessary to examine the direct relation between mothers' characteristics and children's spatial ability in addition to the indirect relations via the home spatial environment.

Conclusion

In summary, this study aimed to better understand the mechanisms underlying mothers' choices to participate in spatial activities with their children. This research is important because it allows researchers and educators to identify mothers who may benefit from additional support in building a higher quality home spatial environment, such as those with low interest in STEM and high levels of general anxiety. We hope that this study's findings will lead to the development of programs and tools that help parents foster their children's spatial learning.

V. GENERAL DISCUSSION

Summary

Children's spatial skills are important for concurrent and later achievement in math and science (Gilligan et al., 2017; Gunderson et al., 2012, Hodgkiss et al., 2017; Hodgkiss et al., 2018; Verdine et al., 2014; Wong, 2017). Since spatial thinking is not formally taught in schools, one proposed mechanism for improving children's spatial skills is to foster these skills in the home setting. However, there is variation in the quantity of spatial learning opportunities that parents engage their children in the home setting. It was hypothesized that part of the reason that variation in parents' promotion of the home spatial environment exists is because parents' own characteristics influence their parenting practices (Elliott & Bachman, 2018; Taylor et al., 2004). Little research has been conducted examiningwhether (1) parents' attitudes influence the home spatial learning environment that they provide to their preschool-aged children and (2) whether these factors relate to their children's intrinsic and extrinsic spatial abilities. This dissertation aimed to fill this gap in the literature.

The goal of this dissertation was to better understand how the early home environment including mothers' characteristics (spatial ability, interest in STEM, and spatial anxiety), mother-child spatial play, and their interaction, influence the development of four- to six-year-old children's intrinsic and extrinsic spatial skills. This dissertation extends previous research that has examined direct and indirect influences on children's spatial skills within the home context (Casey et al., 2014; Dearing et al., 2012) because it examined the effects of mothers' characteristics besides spatial ability, such as mothers' spatial anxiety and interest in STEM, and because it focused on the development of children's intrinsic *and* extrinsic spatial skills, not just children's intrinsic spatial skills. Further, the studies conducted in this dissertation are innovative because spatial tasks that were traditionally paper-and-pencil tasks were adapted to be remote-friendly, and data was collected in a fully remote format offering the opportunity to recruit families across the United States.

Individual Differences in Young Children's Spatial Ability: A Review

Paper 1 provides a comprehensive review of the biological, psychological, and cultural factors that influence children's spatial ability guided by a Relational Developmental Systems (RDS) framework. In this paper, we discussed how parent spatial ability (Dearing et al., 2012; Casey et al., 2014), child motor skill (Frick & Mohring, 2016; Jansen & Heil, 2010; Jansen et al., 2011; Jansen et al., 2013; Jansen & Richter, 2015; Jansen et al., 2016; Lehmann et al., 2014; Pietsch et al., 2017), child working memory and executive function (He et al., 2019; Lehmann et al., 2014), child spatial play (Abad, 2018; Casey et al., 2008; Jirout & Newcombe, 2015), child spatial anxiety (Lauer et al., 2018; Wong, 2017), teacher spatial competence and anxiety (Burte et al., 2020; Gunderson et al., 2013; Ping et al., 2011), parent use of spatial language (Casasola et al., 2020; Ferrara et al., 2011; Pruden et al., 2011), and parent promotion of the home spatial environment (Casey et al., 2014; Ramani & Siegler, 2014; Zippert et al., 2020) all co-act and influence children's spatial development simultaneously. Further, we proposed that the development of spatial thinking occurs as a co-action among all of the mechanisms listed above (among others) over time. To approach spatial development using an RDS framework it isnecessary to use bio-ecological approaches that move away from examining how *one* factorinfluences children's spatial skills and instead explore how *several* factors including genetics and early environments influence young children’s spatial skills together (Casey et al., 2014; Dearing et al., 2012; Pruden et al., 2020). Mediation, moderation, and structural equational modeling can be used to probe how several factors interact to explain individual differences in spatial development. Additionally, most research to date only examines children’s spatial skills at one time point which does not allow us to examine how early experiences affect later spatial ability, and how spatial ability changes over time, which is a key element of developmental research. Thus, the utilization of cross-sectional and longitudinal research studies is necessary.

Beyond the calling to study spatial development through an RDS framework, we identify gaps in the current literature that should be addressed with future studies. First, mechanisms that explain individual differences in children’s intrinsic spatial skills are emphasized whereas mechanisms that explain individual differences in children’s extrinsic spatial skills are largely ignored even though children’s extrinsic spatial skills also contribute to children’s success in math and science (Jirout et al., 2018; Hodgkiss et al., 2017; Hodgkiss et al., 2018; Wong, 2017). Second, most of the research studies to date are correlational in nature and experimental/intervention studies are necessary in order to infer causality. Lastly, there is little research on how parent characteristics and the early home environment predict children’s intrinsic and extrinsic spatial skills, which are explored in papers 2 and 3.

Direct and Indirect Effects of Mother Spatial Ability on Child Spatial Ability: What Role does the Home Environment Play?

Using a bioecological approach, Paper 2 explored (1) whether mother intrinsic and extrinsic spatial ability directly predicted child intrinsic and extrinsic spatial ability, respectively, and (2) whether mother spatial ability indirectly predicted child spatial ability via mothers' choices about toys and mother-child intrinsic spatial play in the home setting. A total of 165 mothers and their 4- to 6-year-old children were recruited to participate in a remote video session with an experimenter. Mothers completed a forced-choice *Intrinsic Spatial Toy Preference Task* gauging their preference for highly spatial versus less spatial toys, a *Home Intrinsic Spatial Environmental Questionnaire* which asked questions about the frequency with which they engage their child in spatial activities at home, a *Mental Rotation Test*, and a *Spatial Scaling Task* adapted for adults. Children were administered the *Picture Rotation Task*, the *Spatial Scaling Task*, and the *Peabody Picture Vocabulary Test*.

Contrary to our predictions, our structural equation models revealed that mother spatial ability did not predict children's spatial ability and that mother toy choice and the home intrinsic spatial environment did not mediate this relation nor were related to children's spatial ability. These null results and other recent findings demonstrating that frequency of spatial play was not related to child spatial ability (Casey et al., 2014; Dearing et al., 2012) do not imply that mothers promotion of the home spatial environment is unrelated to child spatial play but rather that we as a field should consider measuring exposure to spatial language in the home and quality of parent spatial support (e.g., gesturing, providing feedback) while engaging in spatial activities as more accurate descriptions of the home spatial environment. Future research should examine whether mother characteristics influence these aspects of the home spatial environment, instead of frequency of spatial play, and whether these experiences predict children's spatial abilities.

Mothers' Interest and Anxiety in Relation to the Early Home Spatial

Environment

Building from theoretical and empirical evidence that suggest that mothers' own characteristics influence the number of learning opportunities that they offer their children, paper 3 investigated whether mothers' spatial anxiety and interest in STEM predicted the frequency of mother-child spatial play in the home setting. A total of 152 mothers of four- to six-year-old children were recruited from social media platforms and asked to complete an *Intrinsic Home Spatial Environment Questionnaire*, STEM interest questions, an *Intrinsic Spatial Anxiety Questionnaire*, a *State-Trait Inventory Subscale*, and a *Demographics Information Questionnaire.*

Findings showed that mothers' interest in STEM and general anxiety, but not intrinsic spatial anxiety, were significant predictors of frequency of joint spatial play. These findings are in line with our hypothesis that mother characteristics can influence the home environment that mothers provide for their children. Further, these findings support previous work that showed that parents' interest in STEM is related to parent-child engagement in math and science activities in the home setting (Cheung et al., 2020; Junge et al., 2021). Interestingly, this relation was unaffected by child gender. Contrary to research studies conducted in the similar field of mathematics, this study did not find that mothers with high domain-specific anxiety engaged their children in spatial activities less frequently (Berkowitz, 2018). However, there is a possibility that although mothers' spatial anxiety does not influence the frequency of spatial play, it does influence the quality of spatial play. Further research is necessary to determine whether mothers' spatial anxiety influences the amount of scaffolding (e.g., spatial language, gestures, probing) that mothers provide during spatial play. Unfortunately, only the quantity, but not the quality, of the mother-child spatial play was measured in this study. Findings from this study help identify mother characteristics that are worth targeting in future training or intervention studies.

Limitations

Social Desirability Bias. While self-report is commonly used when studying children's early home learning environments (Casey et al., 2014, Dearing et al., 2012; Zippert et al., 2020), it is important to note that mother report of engagement in spatial activities may be flawed due to mothers recalling the amount of spatial play incorrectly or mothers reporting exaggerated amounts of spatial play due to social desirability. Observational studies may provide a more accurate portrayal of children's early home spatial environments.

Only mothers were recruited. Since mothers are typically the primary caregivers and it is difficult to recruit fathers, only mothers were recruited for this dissertation. As a result, this study provides an incomplete view of the home spatial environment. It is assumed that fathers also contribute to their children's home spatial environment and this should be addressed in future studies.

The *Home Intrinsic Spatial Activities Questionnaire.* The *Home Intrinsic Spatial Activities Questionnaire* used in this dissertation is not exhaustive, and only includes twelve spatial toys. Consequently, other aspects of the home spatial environment such as exposure to books and television shows that emphasize spatial content (Gerde et al., 2021), parent use of spatial language (Ferrara et al., 2011; Pruden et al., 2011; Ramani et al., 2015), and parental support during spatial tasks (Casey et al., 2014) are not examined. Spatial experiences that mothers provide outside of the home such as sports, clubs, nature walks, and museum visits are also omitted. A better measure of the home spatial environment should be developed.

Child characteristics beyond spatial ability were not examined. Thisdissertation did not take into account that child characteristics that may influence the decisions that parents make about how often they engage in spatial learning opportunities in the home as well (Elliot et al., 2019). The role of child characteristics in the home spatialenvironment should be investigated in future studies. Also of interest is whether mother characteristics and mother-child spatial play predict children's interest in STEM and spatialanxiety which were not measured in these studies.

Only one time-point was observed. Without longitudinal data, we are not able to make any conclusions about whether early home spatial environments influence later spatial ability. We are also unable to determine directionality. Does the child's home environment determine child spatial ability or does child spatial ability determine the home environment? Although there are many retrospective research studies that ask adults to describe their childhood experiences and then compare those to adult spatial performance (Doyle et al., 2012; Nazareth et al., 2013; Moe et al., 2018), those are subject to flawed participant recall. Thus, longitudinal studies are necessary to examine the relation between engagement in spatial activities and spatial ability both concurrently and as children age.

Implications and Future Directions

This dissertation presents exciting implications for parenting practices, early childhood education, and future research. This research is necessary because it can lead to the development of workshops, trainings, and other tools that may help parents foster their children's spatial learning at home through play. Importantly, it is a first step toward identifying mothers who may benefit from these workshops and trainings, such as those with low interest in STEM and high levels of general anxiety. Building from this dissertation, future research studies can explore whether mothers can be taught how to increase the quality of the home spatial environments that they provide for their children. Since a significant relation between mother spatial ability, mother spatial anxiety, and frequency of mother-child spatial play were not found, observational or qualitative studies are needed to examine whether these mother characteristics predict the quality, notquantity, of joint spatial play. Further, mother characteristics that were not examined suchmothers' beliefs about the importance of spatial thinking can be investigated in relation tothe home spatial environment and, in turn, their children's intrinsic and extrinsic spatial skills. Finally, as previously stated, future studies should also examine the contributions offathers and children to the home spatial environment.

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Table 1. Descriptive statistics for all variables of interest.

Variables	M	SD	Minimum	Maximum
Parent Variables				
Intrinsic Spatial Toy Preference Task	7.34	4.42	1	12
Home Intrinsic Spatial Environment	1.94	0.52	0.08	3.83
Mother Intrinsic Spatial Ability	6.87	11.31	0	12
Mother Extrinsic Spatial Ability	8.67	4.19	3	12
Child Variables				
Child Intrinsic Spatial Ability	8.84	14.97	1	16
Child Extrinsic Spatial Ability	6.73	3.03	3	11
Covariates				
Child Age	5	0.67	4	6
Child Gender	1.49	0.25	1	2
Mother Education	6.42	1.53	2	8
General Home Environment	3.03	0.49	0.9	4.83
Child Receptive Vocabulary	119.19	513.66	39	161

Note. Child gender coded as 1 = female and 2 = male. Mother education coded as 1 = some elementary school, 2 = some high school, 3 = high school graduate/GED, 4 = some college, no degree, 5 = Associates degree (AA, AS), 6 = Bachelor's degree (BA, BS), 7 = Master's degree (MA, MS, Med, MSW, MBA), 8 = Professional degree (PhD, EdD, MD).

Table 2. Direct and indirect effects in Model 1

Outcome	Predictor	B (β)	SE_{boot}	†	p-value	L 95%CI	U 95%CI
Mother Toy Choice (M_1)	Mother Intrinsic Spatial Ability (X, a_1)	0.07	0.06	1.27	0.20	-0.02	0.16
Home Intrinsic Spatial Environment (M_2)	Mother Intrinsic Spatial Ability (X, a_2)	0.01	0.02	0.37	0.71	-0.02	0.04
Child Intrinsic Spatial Ability (Y)	Mother Toy Choice (M_1, b_1)	0.02	0.16	0.10	0.92	-0.25	0.28
	Home Intrinsic Spatial Environment (M_2, b_2)	-0.35	0.61	-0.58	0.56	-1.35	0.65
	Mother Intrinsic Spatial Ability (X, c)	-0.11	0.13	-0.87	0.38	-0.32	0.10
	Covariates						
	Child Age	1.32	0.64	2.06	0.04	0.27	2.38
	Child Gender	-0.25	0.74	-0.34	0.74	-1.46	0.97
	Mother Education	0.34	0.34	0.98	0.33	-0.23	0.89
	General Home Environment	0.16	0.61	0.26	0.79	-0.84	1.16
	Child Receptive Vocabulary	0.04	0.03	1.45	0.15	-0.01	0.09
	Total Effect (c)	-0.11	0.13	-0.90	0.37	-0.32	0.09
	Indirect Effect M_1 (a_1b_1)	0.001	0.02	0.07	0.94	-0.02	0.03
	Indirect Effect M_2 (a_2b_2)	-0.002	0.01	-0.18	0.86	-0.03	0.02
	Total Indirect Effect ($a_1b_1 + a_2b_2 = c - c'$)	-0.001	0.02	-0.07	0.95	-0.03	0.03

Note. All results control for child age, child gender, mother education, general home environment, and child receptive vocabulary. †Ratio of coefficient to SE_{boot}. Presence of the effect is determined by bias corrected bootstrap (1000 iterations) to account for possible asymmetry of the sampling distribution. An effect is present if the confidence interval does not cover zero. L = Lower; U = Upper; CI = 95% confidence interval.

Table 3. Direct and indirect effects in Model 2

Outcome	Predictor	B (β)	SE_{boot}	†	p-value	L 95%CI	U 95%CI
Mother Toy Choice (M_1)	Mother Extrinsic Spatial Ability (X, a_1)	0.14	0.08	1.71	0.09	0.01	0.27
Home Intrinsic Spatial Environment (M_2)	Mother Extrinsic Spatial Ability (X, a_2)	0.02	0.03	0.81	0.42	-0.02	0.06
Child Extrinsic Spatial Ability (Y)	Mother Toy Choice (M_1, b_1)	-0.02	0.07	-0.27	0.79	-0.14	0.10
	Home Intrinsic Spatial Environment (M_2, b_2)	0.40	0.23	1.73	0.08	0.02	0.79
	Mother Extrinsic Spatial Ability (X, c)	0.06	0.08	0.80	0.43	-0.06	0.18
	Covariates						
	Child Age	0.11	0.28	0.40	0.69	-0.35	0.57
	Child Gender	-0.01	0.31	-0.03	0.98	-0.52	0.50
	Mother Education	0.14	0.12	1.21	0.23	-0.05	0.33
	General Home Environment	-0.16	0.26	-0.62	0.54	-0.60	0.27
	Child Receptive Vocabulary	0.02	0.01	1.66	0.10	0.00	0.04
	Total Effect (c)	0.07	0.08	0.86	0.39	-0.06	0.19
	Indirect Effect M_1 (a_1b_1)	-0.003	0.01	-0.22	0.83	-0.02	0.02
	Indirect Effect M_2 (a_2b_2)	0.008	0.01	0.64	0.52	-0.01	0.03
	Total Indirect Effect ($a_1b_1 + a_2b_2 = c - c'$)	0.01	0.02	0.31	0.76	-0.02	0.04

Note. All results control for child age, child gender, mother education, general home environment, and child receptive vocabulary. †Ratio of coefficient to SE_{boot}. Presence of the effect is determined by bias corrected bootstrap (1000 iterations) to account for possible asymmetry of the sampling distribution. An effect is present if the confidence interval does not cover zero. L = Lower; U = Upper; CI = 95% confidence interval.

Table 4. Paper 3:
Descriptive statistics by measure.

Measure	*M*	*SD*	Min	Max
Intrinsic Spatial Anxiety	.88	.52	0	2.42
General Anxiety	.78	.48	0	2.25
STEM Interest	1.04	.91	0	3
Mother-Child Spatial Play	1.89	.73	.08	3.83

Table 5. Paper 3:
Correlation matrix for all measures of interest.

Measure	1	2	3	4	5
1. Intrinsic Spatial Anxiety	-				
2. General Anxiety	.28***	-			
3. STEM Interest	-.19*	.03	-		
4. Mothers' Education	-.07	-.08	.17*	-	
5. Mother-Child Spatial Play	-.11	-.34***	.20*	.14	-

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

Table 6. Paper 3:
Multiple regression model for frequency of mother-child spatial play based on the following predictors: intrinsic spatial anxiety, general anxiety, STEM interest, and mother's education.

Measure	b	SE	*p*
Intrinsic Spatial Anxiety	.04	.11	.71
General Anxiety	-.53	.12	<.001***
STEM Interest	.16	.06	.01**
Mother's Education	.05	.44	.31

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

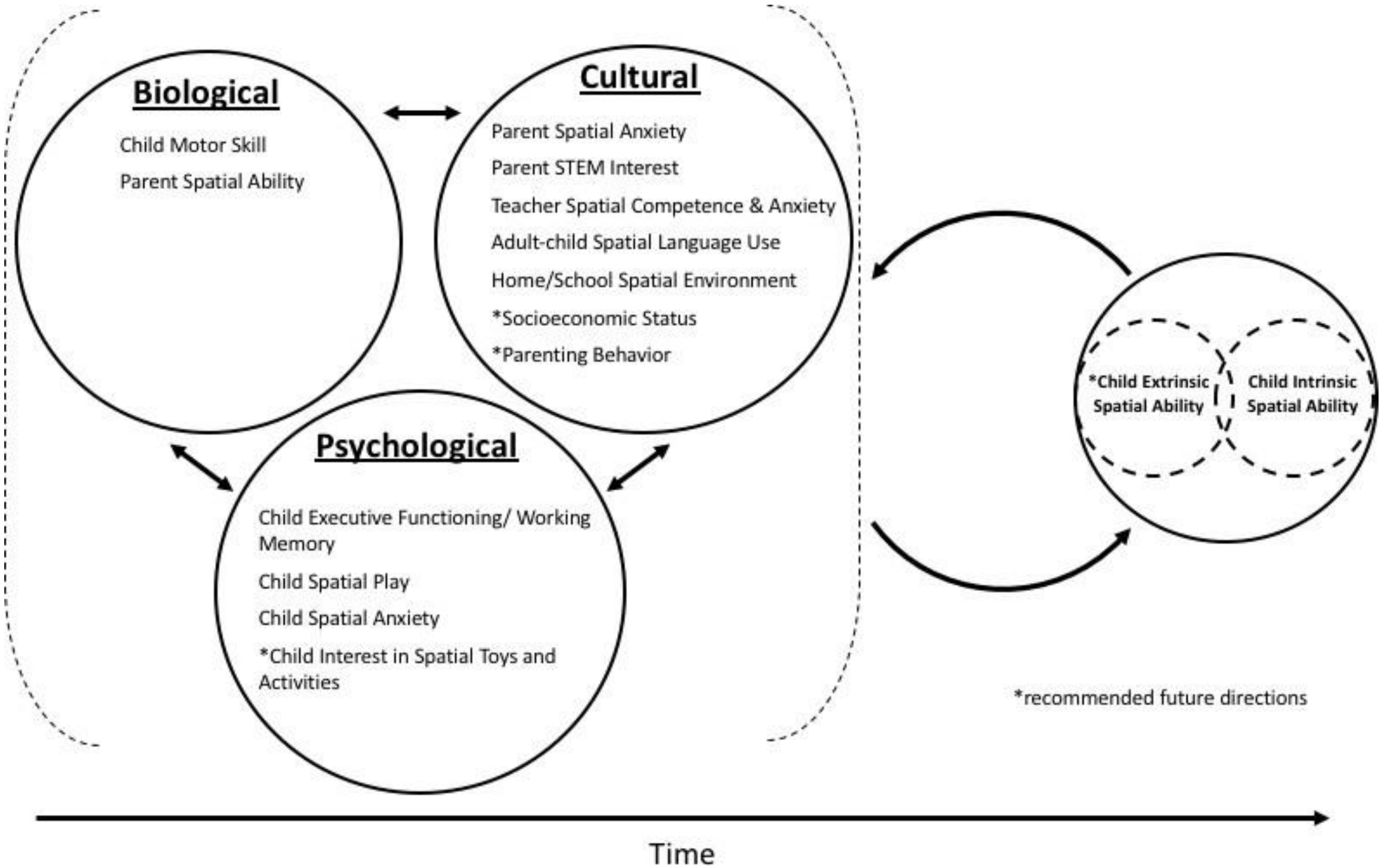

Figure 1. Paper 1: Spatial ability as the result of co-actions among biological, psychological, and cultural factors. Mechanisms with an asterisk are not reviewed in this paper but are identified as potential mechanisms to be explored in future research studies.

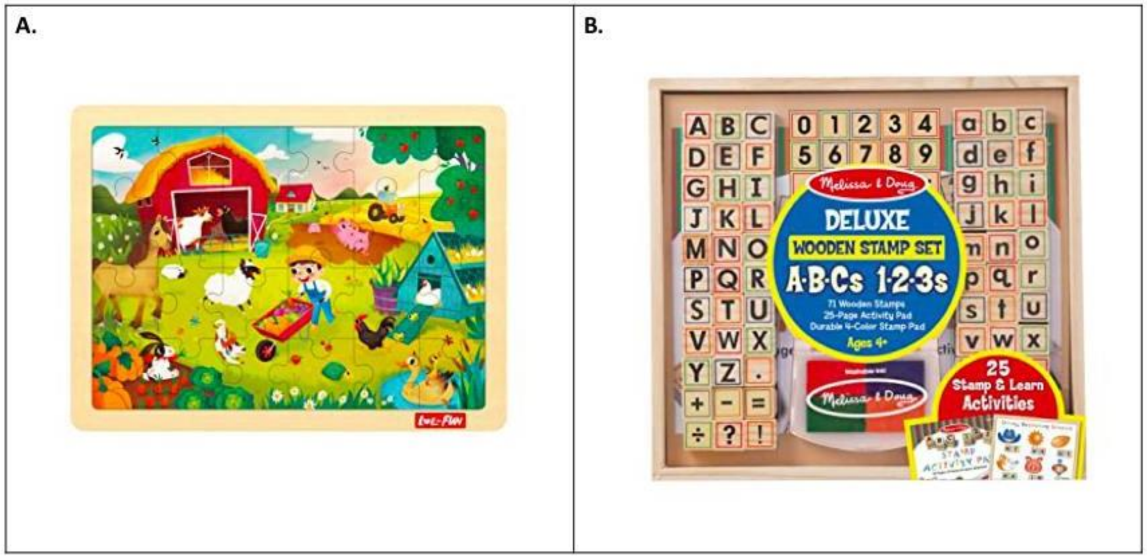

Figure 2. Paper 2: Sample item from the *Intrinsic Spatial Toy Preference Task.*

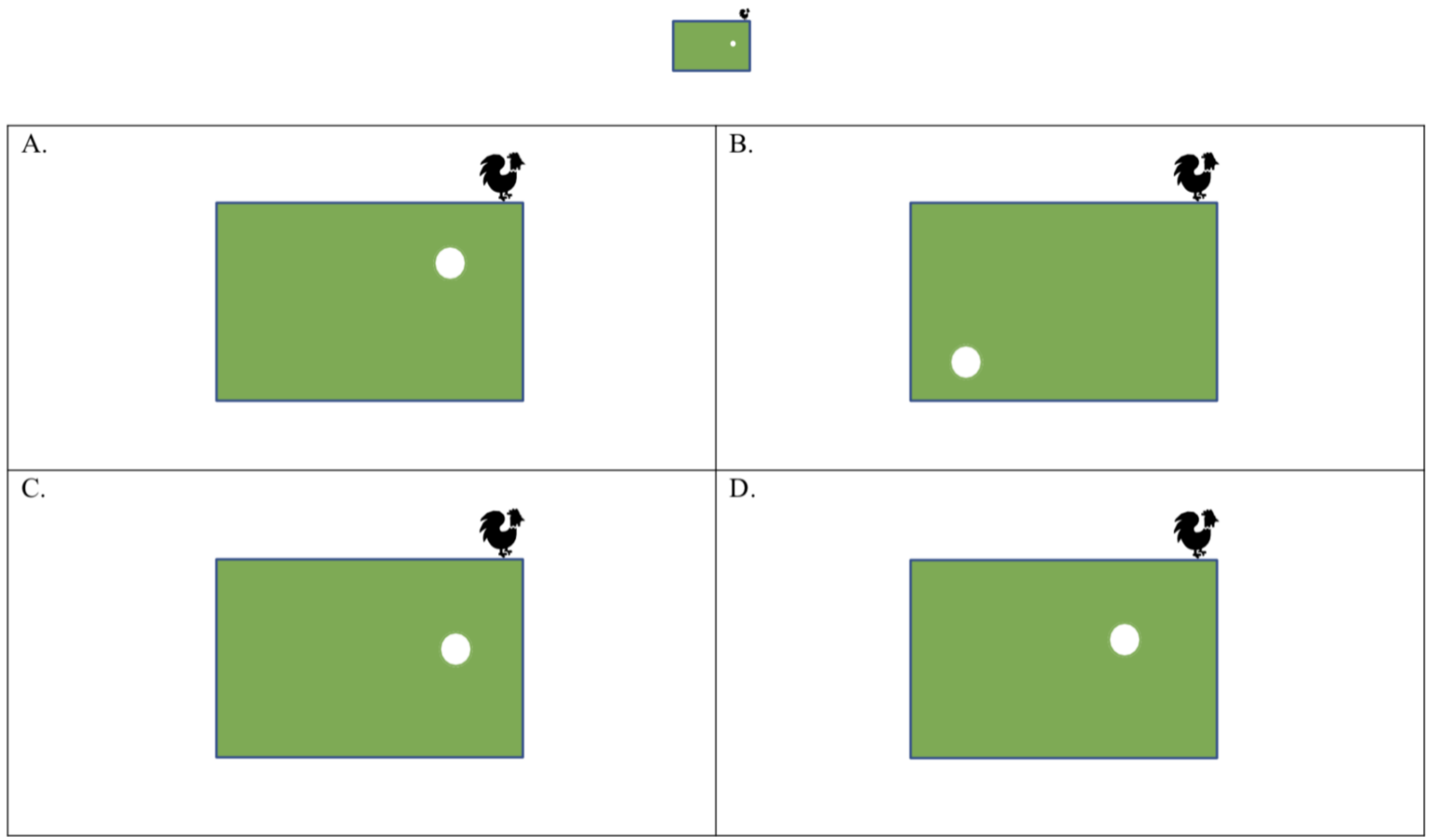

Figure 3. Paper 2: Sample item from adult version of adapted *Spatial Scaling Task*.

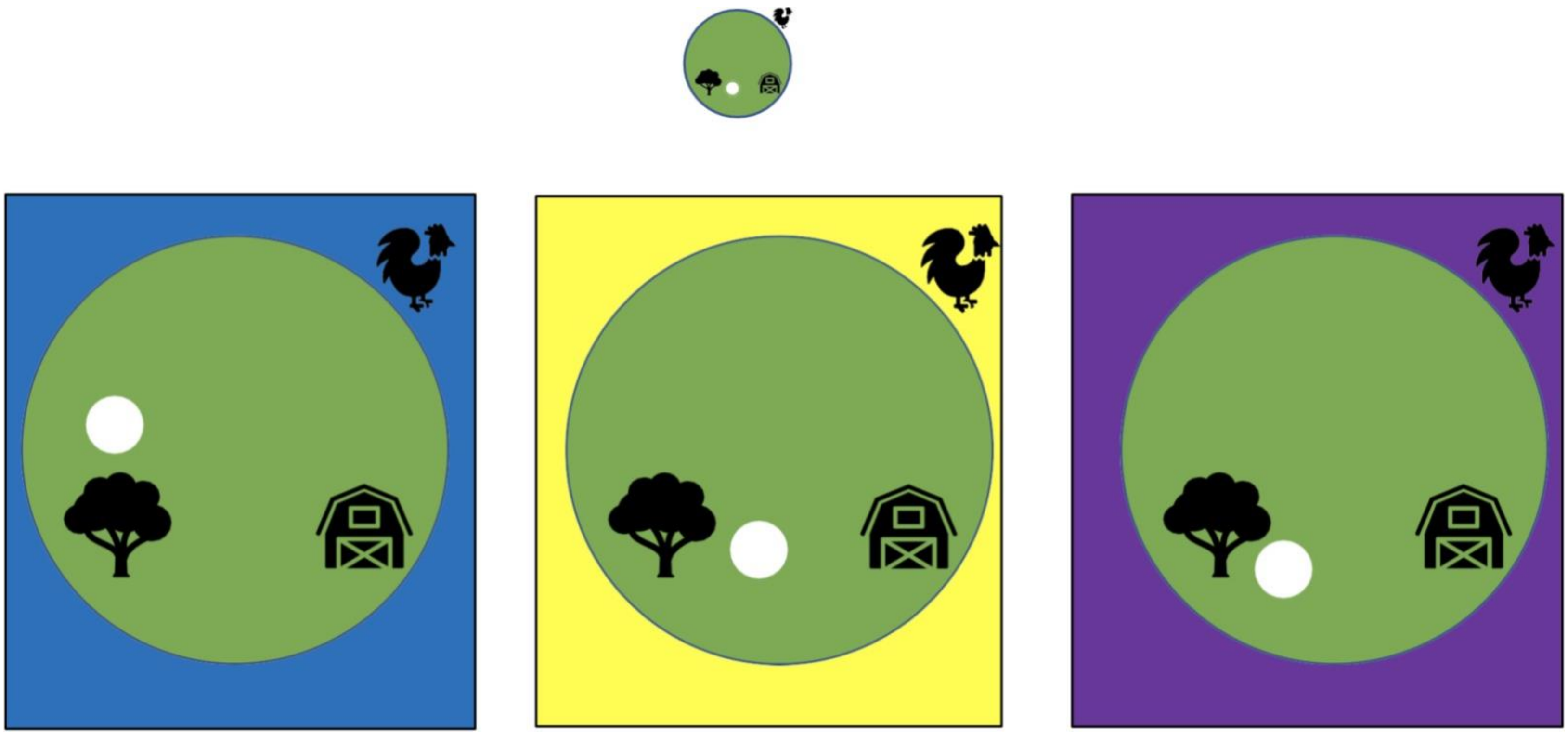

Figure 4. Paper 2: Sample item from child version of adapted *Spatial Scaling Task*.

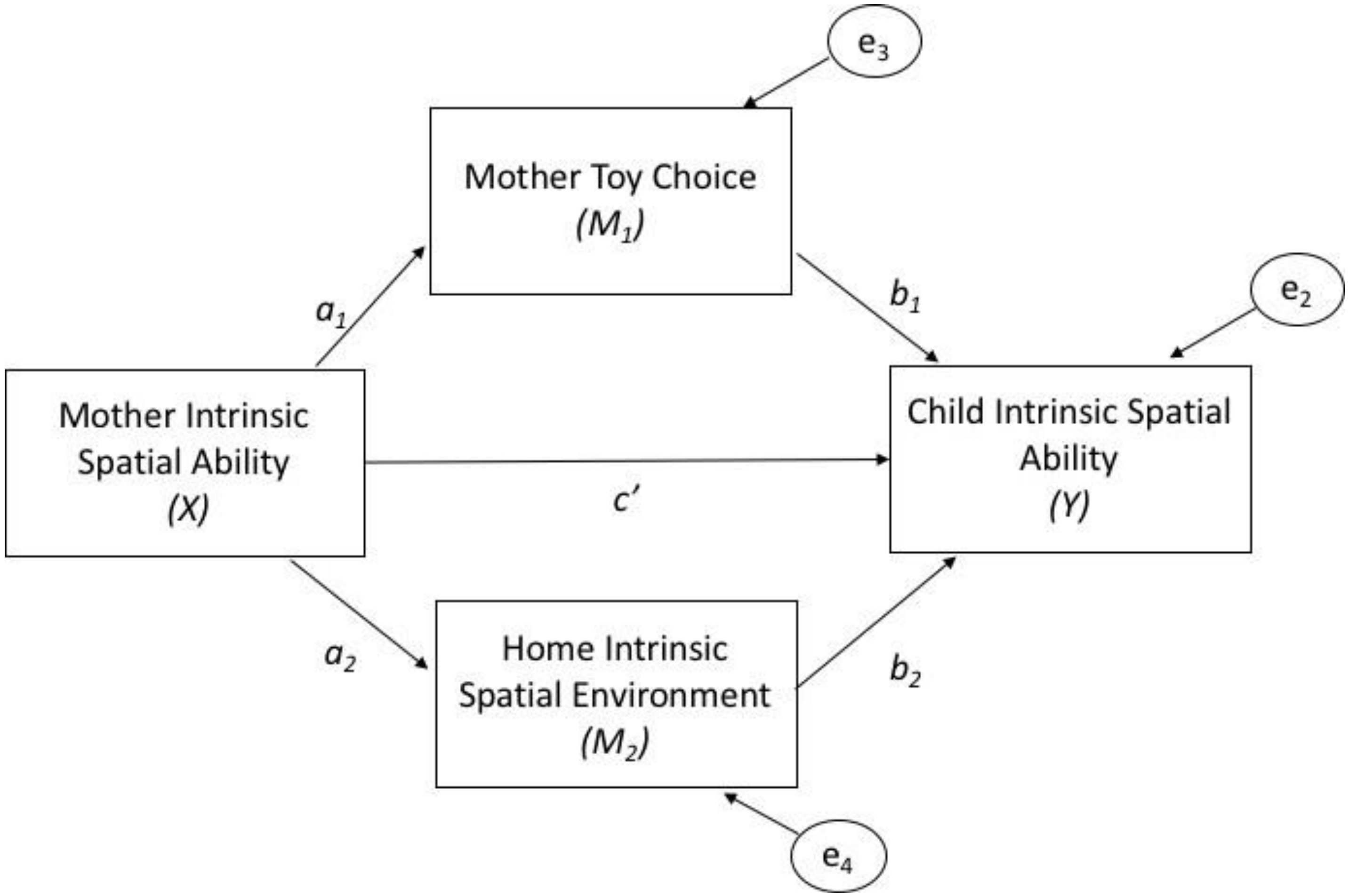

Figure 5. Paper 2: Model testing direct and indirect influences on child intrinsic spatial ability.

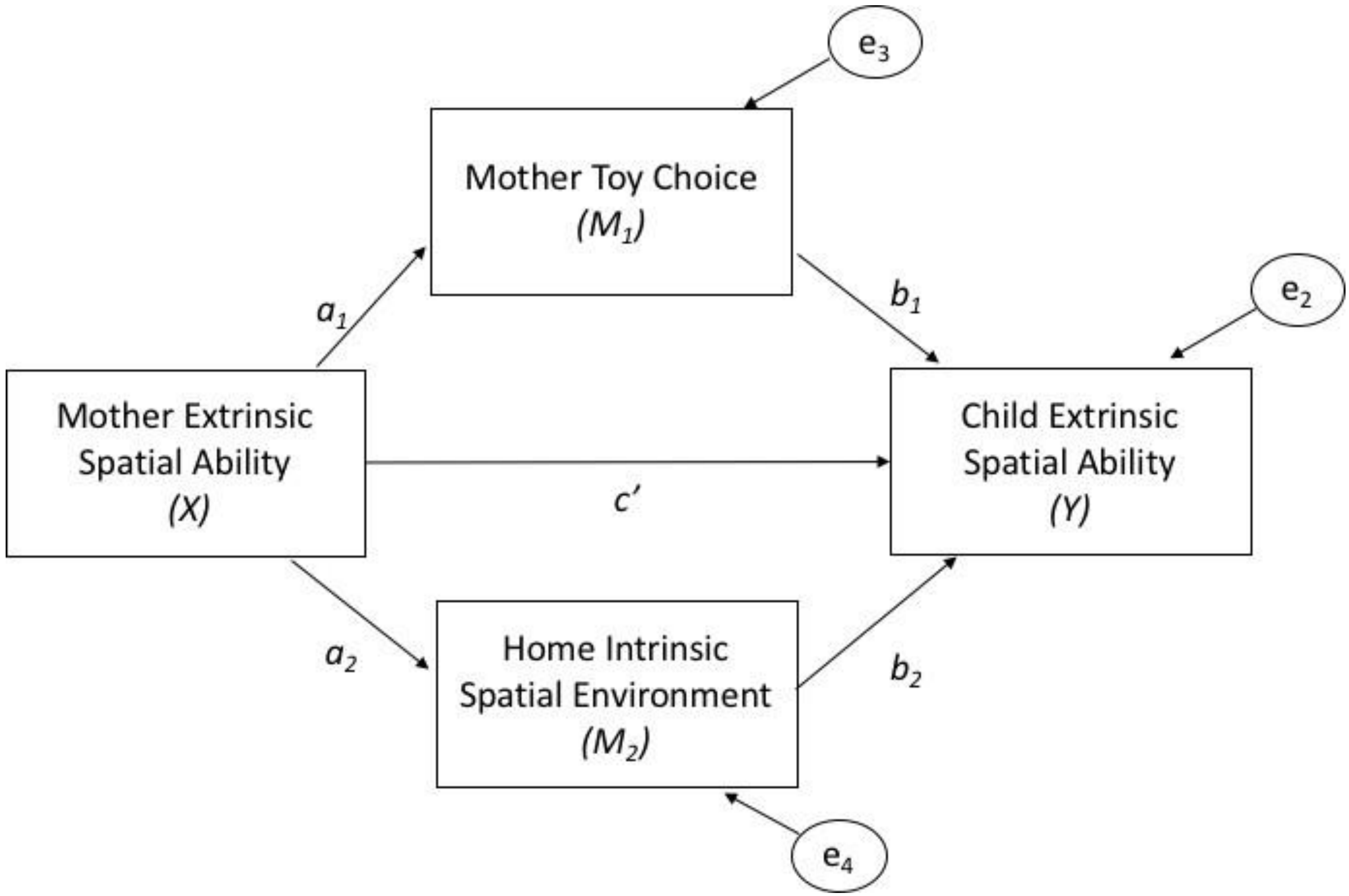

Figure 6. Paper 2: Model testing direct and indirect influences on child extrinsic spatial ability.

On average, how often do you **play with magnetic construction toys** with your child outside of school?

Figure 7. Paper 3: Sample item from the *Home Intrinsic Spatial Activities Questionnaire.*

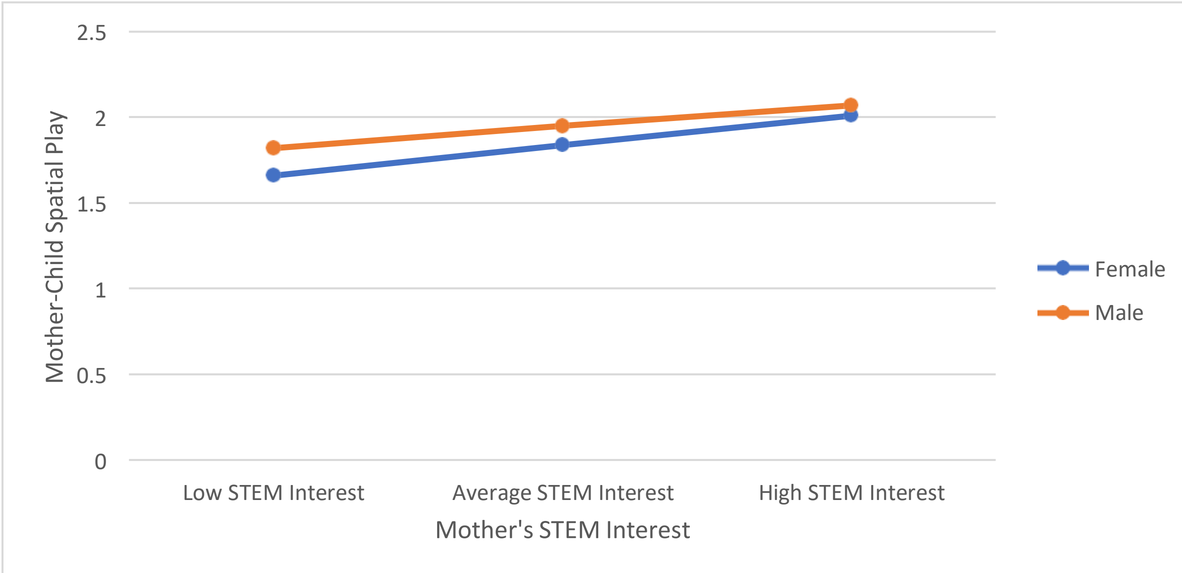

Figure 8. Paper 3: Moderating effect of child gender on the relation between mothers' interest in STEM and mother-child spatial play.

VITA

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PUBLICATIONS AND PRESENTATIONS

Garcia, N. L. & Hamilton, M. (2015, March). *Do Bilinguals Always Have Superior Executive Functioning?* Presented at the 2015 Eastern Psychological Association Conference, Philadelphia, Pennsylvania.

Dick, A. S., Garcia, N. L., Pruden, S. M., Thompson, W. K., Hawes, S. W., Sutherland, M., Riedel, M., Laird, A., & Gonzalez, R. (2018, August). *No bilingual advantage for executive function: Evidence from a large sample of children in the Adolescent Brain and Cognitive Development (ABCD) Study.* Poster presented at the 2018 Flux Congress, Berlin, Germany.

Garcia, N. L., Warman, R., Perera, K., Soto-Harrison, E., & Pruden, S. M. (2019, March). *Contributions of Executive Function to Spatial Thinking in Preschool Children.* Presented at the 2019 Society for Research in Child Development Conference, Baltimore, Maryland.

Dick, A. S., Garcia, N. L., Pruden, S. M., Thompson, W. L., Hawes, S. W., Sutherland, M. T., Riedel, M. C., Laird, A. R., & Gonzalez, R. (2019). No evidence for a bilingual executive function advantage in the ABCD study. Nature Human Behavior, 3, 692-701. https://doi.org/10.1038/s41562-019-0609-3

Garcia, N. L., Pruden, S. M., & Dick, A. (2019, October). *Contribution of Executive Function to Individual Differences in Preschool Children's Spatial Thinking.* Presented at the 2019 Cognitive Development Society Bi-Ennial Meeting, Louisville, Kentucky.

Pruden, S. M., Nazareth, A., Abad, C., Odean, R., Bravo, E., & Garcia, N. (2020). Motor and space: On the development of spatial thinking. In S. Hupp & J.D. Jewell (Eds.), The Encyclopedia of Child and Adolescent Development. John Wiley & Sons. https://doi.org/10.1002/9781119171492.wecad029

Perera, K., Garcia, N. L., & Pruden, S. M. (2020, October). *Spatial Ability and STEM Achievement.* Presented at the 2020 Undergrad Research FIU Research Conference, Miami, Florida.

Perera, K., Garcia, N. L., & Pruden, S. M. (2020, November). Spatial Ability and STEM Achievement. Presented at the Psychonomic Society 61st Annual Meeting, Virtual Meeting.

Garcia, N. L., Dick, A. S., Hayes, T., & Pruden, S. M. (2021, February 25). Direct and indirect effects of parent spatial ability on child spatial ability: What role does the home environment play? Stage 1 Registered Report at Developmental Science, https://osf.io/87ka4/

Garcia, N. L., Pruden, S. M., and Dick, A. S. (2021, April). Contributions of Executive Functions to Spatial Thinking in Preschool Children. Graduate Student Appreciation Week Scholarly Forum, Virtual Meeting.

Garcia, N. L., Rengel-Isea, M., Bowley, H., & Pruden, S. M. (2021, November). Factors that Influence Mother-Child Spatial Play. Harvard Women in Psychology Trends in Psychology Summit.