The Role of Play and Adult Guidance in Children's Spatial Development

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Abstract

When children play with toys like blocks and puzzles, they engage in spatial reasoning—mentally considering objects in space and their relations to each other and their environment. Spatial play is associated with improvement in spatial skills (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014), which are a valuable contributor to success in STEM fields (Stieff & Uttal, 2015; Wai et al., 2009). However, it is unclear whether spatial play *causes* improvement in spatial skills. Past research on spatial play has focused on physical toys, yet many common childhood activities now exist as popular digital games. Furthermore, parents play an important role in their children's spatial development but may behave differently when spatial play is physical versus digital. This dissertation investigated how mothers and children engage together in physical and digital spatial play, and whether such play can improve children's spatial reasoning. In Study 1, 60 five- and six-year-olds (*M* = 71.3 months, *SD* = 7.4 months) and their mothers played with closely matched physical and digital spatial games and mother-child spatial language and mothers' question-asking were coded. Mothers and children used more spatial language, and mothers asked more questions, during physical play than digital play. Mothers and children also showed similar patterns in the types of spatial language they used within each context. To assess whether spatial play advances spatial reasoning, Study 2 enrolled 50 kindergarten and first-grade students (*M* = 77.8 months, *SD* = 8.2 months) in a classroom-based spatial play intervention, during which children played with either physical spatial, digital spatial, or non-spatial toys twice a week for three weeks (6 hours total). There were no effects of physical or digital spatial play on children's spatial skills. Together, these studies revealed that physical and digital spatial play prompt different behaviors in mother-child dyads, but a short-term playful intervention does not impact children's spatial development.

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Chapter 1 – Introduction

Overview

When a child plays with a set of blocks, she is doing more than just building a miniature structure. As she considers the position of each block, she engages in spatial reasoning—mentally considering objects in space and their relations to each other and their environment. For example, she can use mental rotation to envision possibilities for block placement based on their shape and position. She can use spatial visualization to imagine what the structure will ultimately become. She can describe her actions to others using spatial language. The use of spatial reasoning during activities like these characterizes them as spatial play.

And increasingly, she can do all these things digitally as she plays a game like *Tetris* or *Minecraft*. Digital devices are nearly universal in children's lives: 98% of children under the age of 8 have at least one in the home and 37% of 5- to 8-year-olds use digital devices daily (Rideout, 2017). Much of the market for touchscreen applications (apps) has focused on children, with 72% of the top 100-selling Apple Store apps geared specifically towards preschool and elementary-aged children (Shuler, 2012). Out of all these options aimed towards children, the two best-selling video games of all time are both spatial: the classic computer game *Tetris* and the more recently popular *Minecraft* (Peckham, 2016). Yet despite their popularity, researchers have only just begun to examine the educational potential of digital games.

Spatial play with physical toys is associated with improvement in spatial skills (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014), and spatial skills are considered important to success in the fields of science, technology, engineering, and mathematics (STEM; Stieff & Uttal, 2015; Wai et al., 2009). However, it is unclear whether spatial play can directly support children's learning by providing practice in spatial reasoning. Past research on spatial play has focused on physical toys, but with the increasing popularity of digital games, it is important to understand whether children engage similarly with physical and digital spatial materials. Furthermore, parents play an important role in their children's spatial development but may behave differently when spatial play is physical versus digital. This dissertation addressed these gaps, investigating how mothers and children engage together in physical and digital spatial play, and whether such play can improve children's spatial reasoning skills. As one of the first to ask these questions, the present studies aimed to clarify the value of spatial play, which could prove an inexpensive and easy way to foster spatial reasoning from a young age.

As background, I first review the literature on spatial reasoning and spatial play. Then I describe recent research on children's learning from digital media, including digital spatial games. I next consider parents as social partners in their children's learning and play, focusing on two specific mechanisms: spatial language and question-asking. Finally, I consider how children engage in spatial play with their peers.

Spatial Reasoning and Spatial Play

Spatial reasoning is an amorphous concept, in that there is no precise definition agreed on by all, or clear rules about what counts as a spatial ability (Newcombe & Shipley, 2015). Generally, spatial information concerns objects and their shapes, locations, paths through the environment, and relations to other objects. We engage in spatial reasoning when we read a map, pack a box, or put together furniture. Spatial skills are also important for visual and cognitive processes such as reading graphs or understanding complex diagrams. Spatial skills develop extensively during early childhood (e.g., Davies & Uttal, 2007; Frick & Newcombe, 2012) and are malleable (Uttal et al., 2013).

Longitudinal studies link spatial abilities to later performance in mathematics and science for children, adolescents, and adults (Shea et al., 2001; Verdine et al., 2017; Wai et al., 2009; Wolfgang et al., 2001). Children with stronger spatial abilities, such as visuospatial working memory and mental rotation, consistently perform better on math tasks (e.g., Geary et al., 2007; Gunderson et al., 2012; Kyttälä et al., 2003; Lachance & Mazzocco, 2006). Adolescents with stronger spatial skills are more likely to acquire university degrees in STEM fields and choose math-focused careers in adulthood (Shea et al., 2001; Wai et al., 2009). Cheng and Mix (2014) found that mental rotation training improved 6- to 8-year-olds' ability to solve mathematical calculations; however, the effects may be short-lived (Hawes et al., 2015). Still, this research suggests that intervening on children's spatial learning might effectively support their broader STEM skills.

One such way to intervene on children's spatial reasoning is through play. Popular childhood toys, like blocks and puzzles, engage spatial skills (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014). Consequently, block play is hypothesized to support a range of skills underlying both spatial reasoning and math, including estimation, measurement, patterning, part-whole relationships, visualization, symmetry, transformation, and balance (Casey & Bobb, 2003). For example, children's block assembly skills predict their spatial and math performance (Caldera et al., 1999; Verdine et al., 2017; Verdine, Golinkoff, Hirsh-Pasek, Newcombe, et al., 2014; Wolfgang et al., 2001). With regards to puzzles, Levine et al. (2012) observed children's puzzle play at home between the ages of 2 and 4 years and found that those who played frequently with puzzles performed better on a spatial transformation task at age 4 and a half. Jigsaw puzzle performance also correlates highly with children's mental rotation, spatial perception, and spatial visualization skills (Verdine et al., 2008). Similarly, Jirout and

Newcombe (2015) found that children who often played with puzzles and blocks scored higher on general spatial ability than children who played with them less frequently. Play with toys from other categories, like drawing materials or sound-producing toys (e.g., rattles, drums), had no effect on children's spatial ability.

Since spatial skills develop substantially in early childhood, a time when children often engage in spatial play, it would make sense for their play experiences to lead to spatial learning. Few experimental studies have been conducted to evaluate this premise, but those that have appear promising. Casey et al. (2008) introduced a block building intervention to kindergarten classrooms and found it improved children's spatial visualization, particularly when embedded in a narrative. Relatedly, children who played a numerical board game improved on number line estimation (Ramani & Siegler, 2008; Siegler & Ramani, 2008), a spatial task that underlies mathematical understanding. However, further research is needed to demonstrate a causal link between spatial play and spatial reasoning and to determine the mechanisms driving this relationship.

Learning From Digital Media

Digital media differs from traditional forms of media, such as television, in important ways. Touchscreen devices are interactive, offer a wide range of activities, and are highly portable, allowing them to be used anywhere at any time. Children frequently use them to play games (Rideout, 2017), but it remains unclear how successfully children can learn from digital games. Age seems to be an important factor, because children under the age of 3 largely do not transfer information learned on a touchscreen to the real world (Moser et al., 2015; Zack et al., 2009, 2013). This might be because encoding information in one medium and then transferring it to another medium requires memory flexibility that is lacking in infancy (Barr, 2013). But children over the age of 4 show more success at transferring learned information from touchscreens to real-world contexts. First-graders who used a mathematics app weekly showed increased math achievement six months later (Berkowitz et al., 2015), and 4- to 6-year-olds who learned to solve a difficult cognitive puzzle (the Tower of Hanoi) on an app were able to transfer this skill to a physical version of the puzzle (Huber et al., 2016). Kwok et al. (2016) compared learning from in-person instruction to learning from a touchscreen app, and found that 4- to 8-year-old children learned novel animal facts equally well from either source. However, in my own research, 5-year-olds failed to learn from a geography app by themselves but were more successful when an experimenter guided their learning from the app, suggesting that social interaction was necessary to learn from the app (Eisen & Lillard, 2020). This idea will be elaborated on in the coming section on social partners.

Digital Spatial Learning

As mentioned in the Overview, the two best-selling video games of all time are both spatial. *Tetris* and *Minecraft* are each essentially about block building, although *Minecraft* takes the concept much further than is possible in the real world. There is limited evidence that digital spatial games can improve spatial skills. Third-graders who played *Tetris* for one month improved on mental rotation when compared to a control group that played a non-spatial game (De Lisi & Wolford, 2002). In a similar investigation, fifth-graders who played a digital version of *Pentominoes*, a puzzle game where geometric shapes are moved around to fit into a larger shape, improved on spatial perception, mental rotation, and spatial visualization after playing (Yang & Chen, 2010). Fifth-graders also improved their performance on dynamic spatial tasks after playing a video game that involved directing a marble through a maze (Subrahmanyam & Greenfield, 1994).

In adults, video game use has been linked to higher levels of spatial cognition (see Spence & Feng, 2010 for a review). For example, undergraduates who spent 10 hours playing a first-person-shooter video game performed better on a mental rotation task (Feng et al., 2007). This was especially true for female students, whose baseline levels were lower than those of male students. Undergraduates who played *Tetris* for 12 weeks also improved in their mental rotation, with effects comparable to students who were repeatedly tested on mental rotation (Terlecki et al., 2008). The effects of the video game on mental rotation were still evident several months later and even transferred to other spatial tasks like spatial visualization.

Since children between the ages of 5 and 8 years old spend about three hours a day watching television, playing video games, and using mobile devices and computers (Rideout, 2017), it is important to understand the effects of children's screen engagement on their spatial cognition. The present studies expand on the limited prior research by directly comparing how children engage with physical and digital spatial games and the impact of these games on spatial ability.

Parents as Social Partners in Learning

Although children can be independent in their physical and digital play, they also benefit from the inclusion of a social partner. A wide range of research has demonstrated that parents regularly scaffold playful activities in ways that support children's learning. Here, I describe how parents serve as social partners in children's play and media use.

Parents' engagement in children's spatial play, as with all play, falls on a spectrum. At the extremes, parents may lead the activity by building block structures or puzzles themselves while instructing the child (direct instruction), or merely observe the child's play, giving the child full control of the activity (free play). The middle ground, where the child leads the activity but the parent structures it towards a learning goal, is known as scaffolded learning or "guided play" (Weisberg et al., 2016; Weisberg, Zosh, et al., 2013; Yu, Shafto, et al., 2018; Zosh et al., 2018). In guided play, the adult pays attention to the needs of the child in achieving a goal and can provide different levels of scaffolding.

Parents can also play an important role in scaffolding children's use of touchscreens. For example, parents and children in Berkowitz et al. (2015) interacted together with a math app at bedtime and children's math achievement showed particular gains when the parents reported themselves to be anxious about math. Having an adult assist a child in using the app may guide their understanding of the material. When 2.5- and 3-year-olds were taught on a touchscreen to put together puzzle pieces to create a fish shape, they successfully learned from an experimenter demonstrating how to move the pieces on the screen but not from a "ghost demonstration" in which the pieces moved by themselves (Zimmermann et al., 2017). Social interaction is rarely built into children's apps (Hirsh-Pasek et al., 2015) and researchers have just begun to examine co-use of touchscreens as a promising avenue for future research.

Yet adult support does not always influence children's media use in a positive way. When reading e-books, parents often focus on technical aspects, like their child's actions, rather than story content (Chiong et al., 2012; Krcmar & Cingel, 2014; Parish-Morris et al., 2013). Whether this negatively affects children's story comprehension is unclear (Lauricella et al., 2014; Takacs et al., 2014), but it results in lower quality parent-child interactions (Krcmar & Cingel, 2014; Parish-Morris et al., 2013). Similarly, play with e-toys is more likely to be adult-directed rather than child-directed (Bergen et al., 2009). E-toys elicit less overall language from parents and children than traditional toys (Sosa, 2016) and less spatial language from parents

(Zosh et al., 2015). Although touchscreens differ from their media predecessors, these studies of parent-child engagement with electronic books and toys inform the present work.

Undoubtedly, parents occupy an important role in children's play activities and learning. I now focus on two aspects of parent-child interaction that may be especially important for developing spatial reasoning: spatial language and question-asking.

Spatial Language

One type of scaffolding that has been shown to support children's spatial development is spatial language. Spatial language describes the shapes, dimensions, features, locations or orientations of objects in space (Cannon et al., 2007). Parents vary greatly in the amount of spatial language they use while engaging with children. In a longitudinal study of language development, Pruden, Levine, and Huttenlocher (2011) observed ordinary in-home behavior of children and their families for 90 minutes every 4 months, from ages 14 to 46 months. Overall, they found that parents used spatial words an average of 167 times, but the individual variability was vast: the range of spatial terms across all visits was between 5 and 525 times. Parents who used a lot of spatial language had children who used more spatial language, and these children also performed better on spatial transformation and spatial analogy tasks, but importantly, parents' spatial language predicted children's spatial scores through the mediator of children's spatial language (Pruden et al., 2011). Parents' verbal guidance on spatial concepts like perspective (i.e. understanding that objects look different from different angles) is also related to children's performance on spatial tasks (Szechter & Liben, 2004). Parents produce more unique spatial words when interacting with boys than with girls, and boys in turn produce more unique spatial words than girls, but parents' spatial language has been shown to mediate these sex differences (Pruden & Levine, 2017).

Parents’ spatial language is an important part of children’s developing spatial skills, yet it is an open question whether engaging with digital spatial activities impacts parents’ and children’s spatial language. Study 1 addressed this question directly by comparing mother-child spatial language during physical and digital spatial play.

Question-Asking

Another way parents can scaffold their children’s play is by asking questions. It is clear to anyone who has spent time with children that they ask questions often—on average, over 100 questions an hour (Chouinard, 2007) —but parents also regularly direct questions to children (Yu et al., 2017). Although parents most frequently ask questions to gather information, they also employ questions as an educational tool by asking pedagogical questions: that is, questions asked by a knowledgeable person who intends to teach. The knowledge state of the questioner is a crucial component; when 4- and 5-year-olds were asked “What does this button do?” by a knowledgeable teacher compared to an ignorant bystander, they successfully learned the intended information (Yu, Landrum, et al., 2018).

By asking pedagogical questions, parents intend for children to think about the topic being raised. Such questions are a type of pedagogical cue, an indicator that there is information to be learned here (Sage & Baldwin, 2012). Thus, they fit the realm of scaffolding because they serve to support children’s learning. Importantly, pedagogical questions differ from direct instruction in that the onus remains with the child: the parent raises the question but it is up to the child to determine the answer.

To my knowledge, no research has explored question-asking during spatial play, even though such play offers plentiful opportunities for pedagogical questions. Moreover, it is unknown whether parents use questions to scaffold children’s digital play, or how question-asking might differ between physical and digital play contexts. Therefore in Study 1, mothers' questions were evaluated across physical and digital spatial play.

Spatial Play with Peers

Most of the literature on social engagement during spatial play has focused on how parents and other adults interact with children. Yet often, play with blocks, puzzles, and other spatial toys occurs between peers. How do children cooperate in their spatial play to reach shared goals? From research showing that children display more positive peer behavior in school settings that are child-directed, like free play and recess, we might expect that peers will work well together when spatial play is open-ended instead of shaped by teachers (Booren et al., 2012; Vitiello et al., 2012).

Instead, it seems that some level of structure helps support peer interactions. For the block building intervention implemented by Casey et al. (2008) in which groups of three to five children shared materials, teachers in the intervention condition emphasized collaborative block play and children subsequently worked together as teams, correcting each other's block placement but rarely arguing. But in the control condition, where teachers did not structure the activity, children rarely worked together for long and there was less collaborative problem-solving. In another study, child dyads were asked to build a house out of blocks but not explicitly told to do it together (Ramani et al., 2014). Those who coordinated their actions engaged in more spatial talk and built more complex structures. Similarly, preschoolers who engaged cooperatively during play with math-related toys tended to use more math and spatial talk (Zippert et al., 2019).

Children's play with spatial toys can include peers and adults, yet most studies have focused on adult-child interactions. This is equally true for digital media research, in which peer-

peer interactions have been almost entirely ignored. The focus of Study 2, as mentioned previously, was the potential causal relationship between spatial play and spatial reasoning. However, the design of Study 2 provides the opportunity to explore group dynamics during physical and digital spatial play and potential relations to spatial development. Although beyond the scope of this dissertation, I will raise this idea again in the section on Future Directions.

The Present Studies

Spatial reasoning is an important but often neglected component of STEM learning. Spatial skills are sensitive to intervention (Uttal et al., 2013) and one way spatial skills can be improved is through play with spatial toys, such as blocks and puzzles (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014). With the increasing digitization of children's play, it is important to explore the influence of both physical and digital spatial toys, and how adult involvement can enhance learning. This dissertation investigated the impact of physical and digital spatial play in two studies conducted in different settings. Together, these studies sought to understand whether spatial play improves spatial reasoning and how mother-child interactions might serve as a mechanism to support children's physical and digital spatial play.

Study 1 examined how mothers and children engage together in spatial play in a laboratory setting, concentrating on two components of parent-child interaction that prior research suggests are important to learning: spatial language and question-asking. This study offered a close examination of mother-child spatial play, but did not answer the question of whether engaging in spatial play improves children's spatial skills. Thus, Study 2 examined the effects of a three-week school-based spatial play intervention on children's spatial reasoning skills. In this study, children were randomly assigned to play with either physical spatial toys, digital spatial games, or non-spatial toys to assess whether physical or digital spatial play (compared to non-spatial play) increased spatial reasoning.

Chapter 2 - Study One

This study compared how mothers and children interact when engaged in spatial play in physical and digital contexts. Specifically, three primary questions were addressed:

1) Do mothers use more spatial language during physical or digital spatial play?
2) Do children use more spatial language during physical or digital spatial play?
3) Do mothers direct more questions to their children during physical or digital spatial play?

The sample consisted solely of mothers because they continue to be the primary caregivers for most families in the United States (Pew Research Center, 2015), and fathers have rarely participated in past research on parent-child spatial interactions (e.g., Pruden et al., 2011; Szechter & Liben, 2004). Mothers and fathers might be expected to differ in their behavior, since men outperform women in certain spatial tasks, like mental rotation and spatial perception (Linn & Petersen, 1985; Voyer et al., 1995), perhaps in part because of their involvement in "masculine" spatial activities like carpentry and physical sports (Nazareth et al., 2013; Newcombe et al., 1983). Yet fathers and mothers do not necessarily differ in their supportive behavior (Gauvain et al., 2002; Martin et al., 2007), and fathers' spatial support during block building predicts their daughters' math achievement (Thomson et al., 2020). Thus, we expected that mothers' behavior in this study would serve as an appropriate indicator of parent behavior in general.

Mother-child dyads were recorded as they engaged in play with physical and digital tangram puzzles and blocks. The conversations during play were transcribed and the types of words (spatial and non-spatial) spoken by mothers and children were coded, as were the types of questions mothers asked. Children's general spatial ability, receptive vocabulary, and executive function were assessed as control measures, as the latter two are domain-general abilities that correlate with spatial abilities (Verdine et al., 2017).

Based on the extensive literature on parent-child interaction during use of e-books and e-toys (Chiong et al., 2012; Krcmar & Cingel, 2014; Parish-Morris et al., 2013; Sosa, 2016; Zosh et al., 2015), mothers and children were expected to use more spatial language, and mothers were expected to ask more questions, during physical play than during digital play.

Method

Participants

Participants were 60 five- and six-year-old children (M = 71.3 months, SD = 7.4 months, range = 60.8-84.5 months; 30 female) and their mothers. This age range was chosen because during these years, children's spatial reasoning skills develop extensively (Davies & Uttal, 2007; Frick & Newcombe, 2012) and they spend an increased amount of time with digital devices and are more capable of learning from them (Berkowitz et al., 2015; Huber et al., 2016; Rideout, 2017). Data from an additional five children were collected but excluded: four children did not return for a second visit and one child came with a father instead of a mother. An a priori power analysis was conducted using G*Power 3 (Faul et al., 2007), which indicated that 60 mother-child dyads were sufficient to achieve 95% power using a two-tailed test with a small effect size (Cohen's f_2 = 0.25), as has been shown in meta-analyses comparing the effects of e-book and traditional book reading on vocabulary and story comprehension (Takacs et al., 2014, 2015). Children and mothers were drawn from a database of families willing to have their children participate in research. A representative sample of the local population was recruited, resulting in a sample that was 66% White, 13% multiracial, 7% Black, 2% Asian, and 2% Native Hawaiian or Pacific Islander; 10% did not report race. Participants also reported their ethnicity: 80% were non-Hispanic, 5% were Hispanic, and 15% did not report. Parents provided written consent and children verbally agreed to participate, in line with the study's approval from the university's Institutional Review Board.

Materials

Play materials consisted of two types of toys that have been linked to children's spatial reasoning: puzzles and blocks, each presented in a physical form and a digital form. The digital apps were presented on a 1st generation Apple iPad Air with a 9.7 inch (diagonal) display. The physical materials were produced to match the digital apps.

Tangram Puzzles. For the puzzle activities, dyads used the digital app *Dragon Shapes—Lumio Geometry Challenge* and a set of physical tangram puzzles created to match those of the app. The *Dragon Shapes* app contained 4 levels, with 20 individual puzzles in each level that gradually increased in difficulty (80 puzzles total). Each puzzle consisted of a template with an outline of an image surrounded by the shapes necessary to complete the puzzle, which had to be moved on to the outline to create the image (see Figure 1). To replicate this, physical tangram puzzle pieces were cut out of plywood and painted to match the dimensions and colors of the digital puzzle pieces from *Dragon Shapes*: 10 three-inch right triangles (large), 10 two-inch right triangles (medium), 24 one-inch right triangles (small), 20 one-inch squares, and 10 one-and-a-half-inch parallelograms. Laminated 11 by 8.5-inch templates were made for all the puzzles from the *Dragon Shapes* app, with 20 puzzles in each of 4 levels (80 total). The templates were presented in an ordered, loose pile and on the back of each template was written the number and shapes of the pieces needed to complete the puzzle, akin to the shapes surrounding the outline in the app.

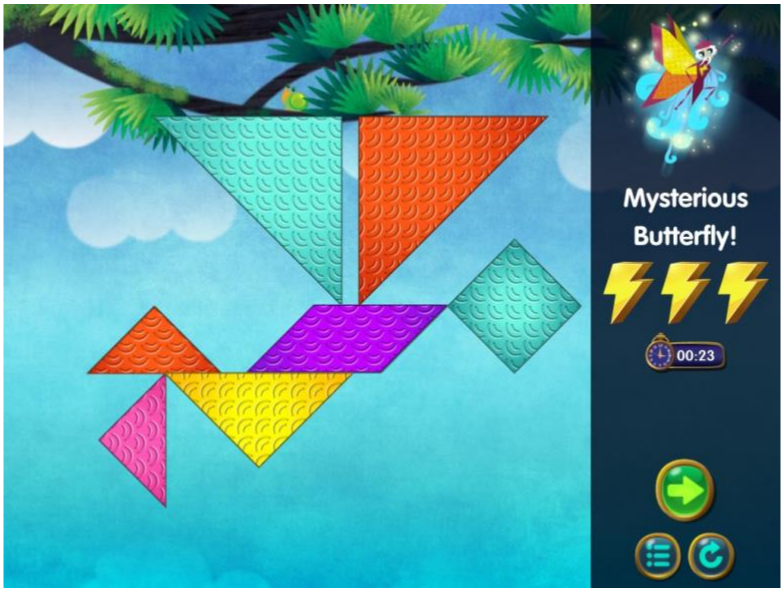

Figure 1. Completed puzzle in the *Dragon Shapes* app.

The levels of the *Dragon Shapes* app were separated by four segments of a narrative story in which a Chinese dragon named Druzzle disappears and a young warrior must follow the dragon shapes left behind to find Druzzle (see Appendix A for full story transcript). Four physical storybooks were created from the narrative in the app and designed to look like real books by using screenshots from the app alongside a written transcript (see Figure 2). Each storybook was bound in a plastic report cover and they were presented together in the same order as the templates.

Figure 2. Example of physical storybook page.

It is important to note that the *Dragon Shapes* app was designed to teach users how to move and rotate pieces within the app during the first two puzzles. The app used spoken and written language to reinforce spatial concepts (e.g., “A triangle has three sides,” and “When you rotate a shape, its properties remain the same.”) and encourage the user after completing a puzzle (e.g., “You have mastered the rotation move!” and “Triangle training!”). The physical puzzle activity did not include such supplements because they were considered features inherent to the app format.

Blocks. For the block activities, dyads used the digital app *Minecraft* and a set of physical *Minecraft* blocks produced by Mattel, Inc. to look like different blocks in *Minecraft*. *Minecraft* is a popular digital game in which users build expansive worlds out of individual cubic blocks. *Minecraft* has several modes, including a Creative Mode that allows users unlimited building resources without the “survival” aspects of other modes; I used Creative Mode in this study so that participants could focus on building structures. Physical *Minecraft* blocks were 60 plastic one-inch blocks designed with various patterns that in the *Minecraft* app denote different materials (e.g., brown blocks for wood, grey blocks for stone, etc.) that were irrelevant for this activity. Dyads were provided with a 15 by 7 inch plastic base on which to place blocks, with grooves separating the block spaces to mimic the invisible grid of the *Minecraft* app. For both block activities, dyads were given laminated images of 20 block structures (with front and side views) built in *Minecraft* to serve as a guide (see Figure 3).

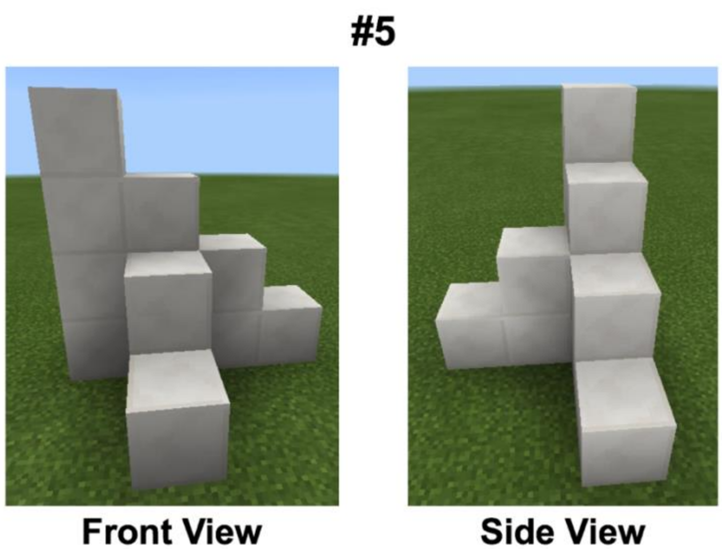

Figure 3. Example of *Minecraft* structure guide page.

An important consideration with the materials was that the physical puzzle pieces were relatively flat whereas the physical blocks were three-dimensional cubes; similarly, the *Dragon Shapes* app used a 2D plane but the *Minecraft* app used a 3D plane, albeit on a flat touchscreen. This difference in dimensionality between the puzzle and block activities was an intentional aspect of the study design to explore the impact of object dimensionality on mother-child language and mothers' question-asking.

Control Measures

General Spatial Ability. General spatial ability was measured using the Block Design task from the Wechsler Preschool and Primary Scale of Intelligence—Fourth Edition (WPPSI-IV, Wechsler, 2012). In this task, children must reproduce patterns using a set of 16 blocks with faces that are red, white, or half red and half white. Block Design is considered a general indicator of spatial ability (Groth-Marnat & Teal, 2000) and is related to children's block and puzzle play (Jirout & Newcombe, 2015). Scores ranged from 0 to 34.

Executive Function. Executive function was measured with Head-Toes-Knees-Shoulders (McClelland et al., 2007; Ponitz et al., 2008), a task in which children must inhibit a prepotent response to produce an alternative, correct response. Children were first taught that when asked to touch their head, they should touch their toes, and vice-versa. They were then tested with 10 commands and scored 2 points for each correct response and 1 point if they started to respond incorrectly but then corrected themselves. If children passed this level by scoring at least 10 points, they moved onto the next level in which a new pairing (knees-shoulders) was added to the previous pairing (head-toes). If children scored at least 15 points, they moved to a final level in which the pairings were switched (head-knees, shoulders-toes). Total scores ranged from 0 to 60.

Verbal Ability. Verbal ability was measured using the Receptive Vocabulary subtest of the WPPSI-IV (Wechsler, 2012), which assesses verbal comprehension by asking children to select the picture that best represents a word read aloud by the experimenter. Scores ranged from 0 to 31.

Questionnaire

Mothers completed a questionnaire on the frequency of their children's exposure to spatial toys (blocks, puzzles, building toys), non-spatial toys (books, dolls/stuffed animals, balls, outside play, drawing materials), and screen media (television, computers, tablets/smartphones) on a 6-point scale ranging from "several times a day" to "once a month or less." Mothers were also asked how important they considered each of the play activities listed above for learning, using a 10-point scale from "not important" to "extremely important." For these questions, responses were averaged to create a category for spatial toys (blocks, puzzles, building toys) and for screen media (television, computers, tablets/smartphones). Next, they reported how many and what types of televisions, computers, smartphones, and tablets were present in their homes, as well as the minutes per week their children used each, and were asked to list the apps or programs their children frequently use. Finally, they were asked whether their children had ever played the digital games *Minecraft* or *Dragon Shapes* before, and if so, for how many minutes per week and on what devices. Mothers were also asked if they had played with physical *Minecraft* blocks or tangram puzzles before, and if so, for how many minutes per week and on what devices. It is important to note that they were asked generally about tangram puzzles because the physical version of *Dragon Shapes* was created by the experimenter for this study. See Appendix B for the full questionnaire.

Procedure

Mother-child dyads were brought into the laboratory for two sessions spaced one week apart. First, children's general spatial ability and executive function (session 1) and receptive vocabulary (session 2) were assessed while mothers completed the questionnaire. Then, dyads were video recorded as they played with one and then the other (10 mins each) of the physical puzzles and blocks, or (for the other half of the sample) one and then the other (10 mins each) of the *Dragon Shapes* and *Minecraft* apps. Each activity was introduced by the experimenter before the dyad began to play (see Appendix C for experimenter scripts). For *Dragon Shapes*, the experimenter first explained how to pass levels, demonstrated placing a piece on a puzzle, and encouraged dyads to start by listening to the beginning of the story; for the physical tangram puzzles, the experimenter introduced the activity using similar language. For *Minecraft*, the experimenter explained how to manipulate blocks and move around the environment and dyads were invited to build structures from the guide or design their own; the physical block activity was introduced similarly (see Appendix C). Dyads returned one week later for a second session in which they played with the other type of material (physical or digital). The order of activities was counterbalanced across the sample both within and across sessions.

Coding

All speech produced by the mothers, children, and app (only *Dragon Shapes* produced language) during the first five minutes of each activity was transcribed by researchers using ELAN (2017) (https://tla.mpi.nl/tools/tla-tools/elan/). The first five minutes were chosen because the beginning of the *Dragon Shapes* and puzzle activities included the first segment of the story, which contained spatial language that was important to capture (see Appendix A). Coders unaware of the hypotheses of the study coded the transcripts for spatial language and maternal questions as described below.

Spatial Language Coding. Mother, child, and app spatial language was coded according to the spatial language coding system developed by Cannon, Levine, and Huttenlocher (2007); see Table 1. Coders identified words that described the following eight spatial categories: (a) spatial dimensions, (b) shapes, (c) locations, (d) spatial orientations or transformations, (e) continuous amount, (f) deictics, (g) spatial features, and (h) pattern. Each spatial word was assigned to a single category. Words that did not fit the parameters of the spatial language coding system were coded as non-spatial. App spatial and non-spatial words were coded only for *Dragon Shapes* because the *Minecraft* app did not produce spoken language.

Table 1

Spatial Language Coding System

Category	Description	Examples
Spatial Dimensions	Size of objects, people and spaces	Big, long, tall, wide, deep
Shapes	Standard form of enclosed two-and three-dimensional object and spaces	Circle, semicircle, triangle, polygon, cube
Location & Direction	Relative position of objects, people, and points in space	At, across, in, bottom, around
Orientation & Transformation	Relative orientation/transformation of objects and people in space	Upside down, upright, turn, flip, rotate
Continuous Amount	Amount of continuous quantities (incl. extent of object, space, etc.)	Whole, section, half, more, none
Deictic	Place deictic /pro-forms (i.e., rely on context to understand their referent)	Here, there, where, somewhere, nowhere
Spatial Features & Properties	Features and properties of 2D and 3D objects, spaces, people, and the properties of their features	Side, curve, flat, face, circular
Pattern	Indicate a person may be talking about a spatial pattern	Design, order, next, increase, repeat

Note. System developed by Cannon, Levine, and Huttenlocher (2007).

Maternal Question Coding. The types of questions asked by mothers were coded according to the system developed by Yu, Bonawitz, and Shafto (2017); see Table 2. Coders first identified whether questions were pedagogical (asking a question for which the answer is known, with the intent to teach), information seeking (eliciting unknown information), or rhetorical (posing a question that does not require an answer). Pedagogical questions were further coded as generic (asking about general concepts or rules) or specific (asking about a specific object, event, or person). Information seeking questions were further coded as specific (asking about a specific object, event, or person), check status (asking about child's needs, opinions, or state), clarification (asking what child said/did), or permission (asking for permission from child). Rhetorical questions were further coded as commands (intending to provoke action) or attention (requesting child's attention or narrating). Coders used the wording of the question and the context of the transcript to sort questions into categories. For ambiguous questions, coders referred to the video to clarify. Each question was assigned to a single category and subcategory.

Table 2

Maternal Question Coding System

Category	Description	Example
Pedagogical	Parent knows answer, intends for child to learn	
Generic	General concepts or rules	"How many sides does a rectangle have?"
Specific	Specific object, event, or person	"Can a triangle fit there?"
Information seeking	Parent seeks information from child	
Specific	Specific object, event, or person	"What are you gonna make?"
Check status	Child's needs, opinions, or state of being	"Do you know what to do?"
Clarification	What child said or did	"What did you say?"
Permission	Permission from child	"Can I build something?"
Rhetorical	Parent does not need verbal answer	
Commands	Intends to provoke action	"Why don't you clean up?"
Attention	Requests attention or narrates to self	"Well?"

Note. System developed by Yu, Bonawitz, and Shafto (2017).

Results

I first focus on how mothers and children use spatial and non-spatial language by comparing across physical and digital play and then all four play activities. Next, I focus on how mothers ask questions, again comparing across physical and digital play and then the four activities. Finally, I report the results of the questionnaire completed by mothers to provide context for their children's home play environments.

Mothers' and Children's Spatial Language During Physical and Digital Spatial Play

Descriptives for mother, child, and app (*Dragon Shapes* only) spatial and non-spatial language are displayed in Table 3. Notably, during the *Dragon Shapes* activity, the app produced 62% of all spatial words during this activity, whereas mothers produced 32% and children produced 6%. Pearson's correlations were conducted to examine relations among outcome variables and control variables; see Appendix D for correlation table. Mothers' language was related to children's language for non-spatial words, $r(58) = .34$, $p = .009$, but not for spatial words, $r(58) = .21$, $p = .106$. Of the three control measures, only spatial ability and verbal ability were related, $r(58) = .31$, $p = .015$. Control measures were not consistently related to outcome measures in the manner expected (see Appendix D).

Table 3

Descriptives for Mother, Child, and App Language

	Total		Physical		Digital	
	M (SD)	Range	M (SD)	Range	M (SD)	Range
Mother						
Total Words	1287.53 (435.58)	284-2788	733.32 (244.68)	121-1615	554.22 (233.14)	163-1173
Non-spatial Words	1183.40 (399.07)	269-2590	670.68 (220.92)	114-1485	512.72 (217.02)	149-1105
Spatial Words	104.13 (46.57)	15-236	62.63 (30.19)	7-152	41.50 (21.76)	7-115
Child						
Total Words	521.73 (260.52)	86-1301	337.70 (164.12)	53-890	184.03 (118.31)	10-484
Non-spatial Words	487.53 (244.09)	77-1210	315.38 (153.54)	50-837	172.15 (111.79)	10-453
Spatial Words	34.20 (19.18)	3-91	22.32 (12.58)	1-53	11.88 (9.44)	0-40
App						
Total Words	169.70 (26.15)	68-229	-	-	169.70 (26.15)	68-229
Non-spatial Words	139.63 (22.98)	45-179	-	-	139.63 (22.98)	45-179
Spatial Words	30.07 (5.45)	13-52	-	-	30.07 (5.45)	13-52

Preliminary analyses indicated no differences in mothers' language to boys and girls, and children's non-spatial and spatial words did not differ by gender, so gender was not considered further in the analyses. Children's spatial ability, verbal ability, and executive function did not consistently relate to mothers' and children's language in the manner expected, so the following analyses controlled only for children's verbal ability to account for the potential influence of children's global vocabulary on language used during sessions. We tested for differences in mothers' and children's spatial and non-spatial language during play using a series of one-way ANCOVAs, with play context (physical, digital) as the within-subjects variable and verbal ability as a covariate.

There was a main effect of context for mothers' spatial words, $F(1, 58) = 4.61$, $p = .036$, $\eta_{p2} = .074$, and children's spatial words, $F(1, 58) = 4.94$, $p = .030$, $\eta_{p2} = .079$. Mothers and children both spoke more spatial words during physical play than during digital play; see Figure 4. There was also a main effect of context for mothers' non-spatial words, $F(1, 58) = 5.88$, $p = .018$, $\eta_{p}^{2} = .092$, and children's non-spatial words, $F(1, 58) = 12.60$, $p = .001$, $\eta_{p}^{2} = .178$; mothers and children spoke more non-spatial words during physical play than digital play.

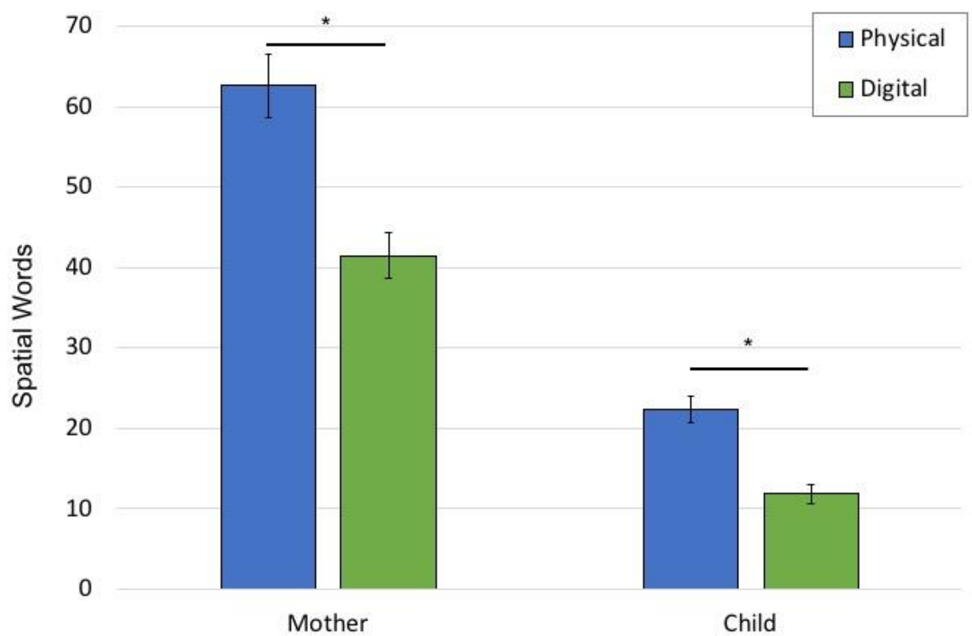

Figure 4. Mothers' and children's spatial words by context. Bars represent standard error. * $p \leq .05$.

Differences in mothers' and children's spatial categories during play were tested using one-way MANOVAs, with play context (physical, digital) as the within-subjects variable and the eight spatial categories as dependent variables; see Figures 5 and 6. During physical play, mothers used a higher proportion of spatial words related to dimensions, $F(1, 59) = 63.32$, $p < .001$, $\eta_{p}^{2} = .518$, and shapes, $F(1, 59) = 96.30$, $p < .001$, $\eta_{p}^{2} = .620$, as did children, dimensions: $F(1, 59) = 27.30$, $p < .001$, $\eta_{p}^{2} = .316$; shapes: $F(1, 59) = 11.34$, $p = .001$, $\eta_{p}^{2} = .161$. In contrast, during digital play, mothers used a higher proportion of spatial words related to location and direction, $F(1, 59) = 16.94$, $p < .001$, $\eta_{p2} = .223$, orientation and transformation, $F(1, 59) = 100.73$, $p < .001$, $\eta_{p2} = .631$, and deictics, $F(1, 59) = 30.64$, $p < .001$, $\eta_{p2} = .342$. Children similarly used a higher proportion of spatial words related to location and direction, $F(1, 59) = 12.89$, $p = .001$, $\eta_{p2} = .179$, and orientation and transformation, $F(1, 59) = 14.64$, $p < .001$, $\eta_{p2} = .199$, but not deictics, $F(1, 59) = 0.14$, $p = .712$, $\eta_{p2} = .002$. There were no differences across context for the proportion of mothers' and children's spatial words related to continuous amount, features and properties, and patterns (all *p*s $\geq .493$).

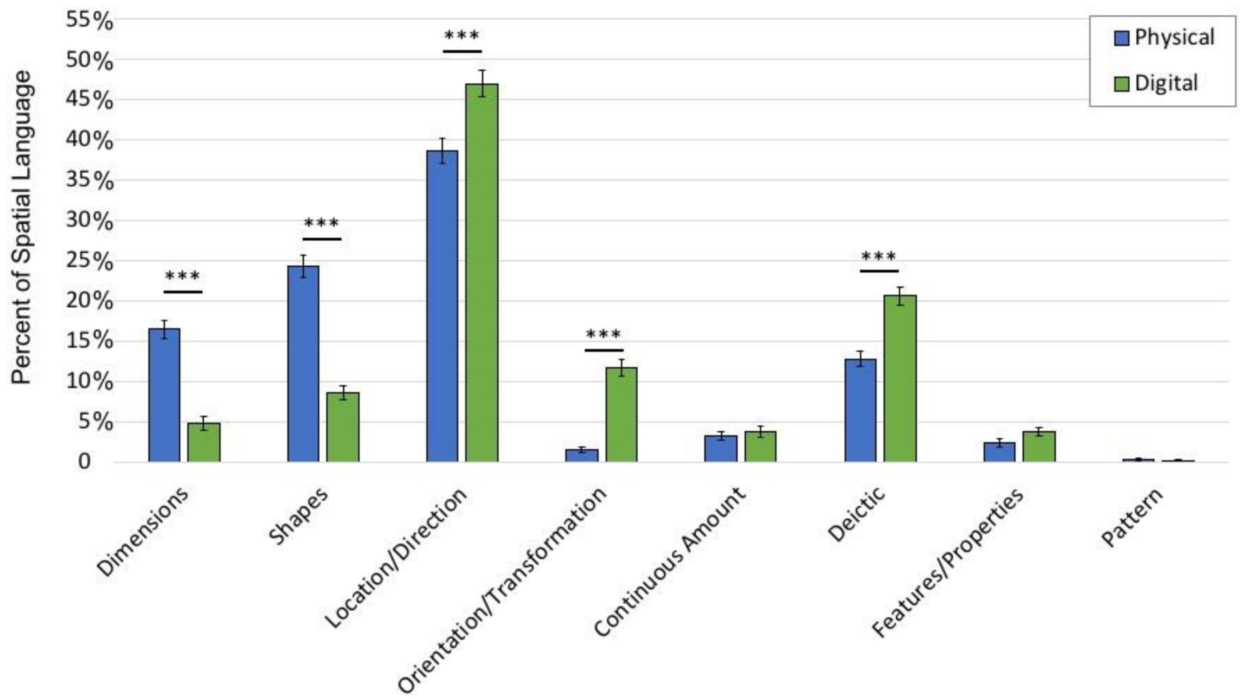

Figure 5. Mothers' spatial categories by context. Bars represent standard error. *** $p \leq .001$.

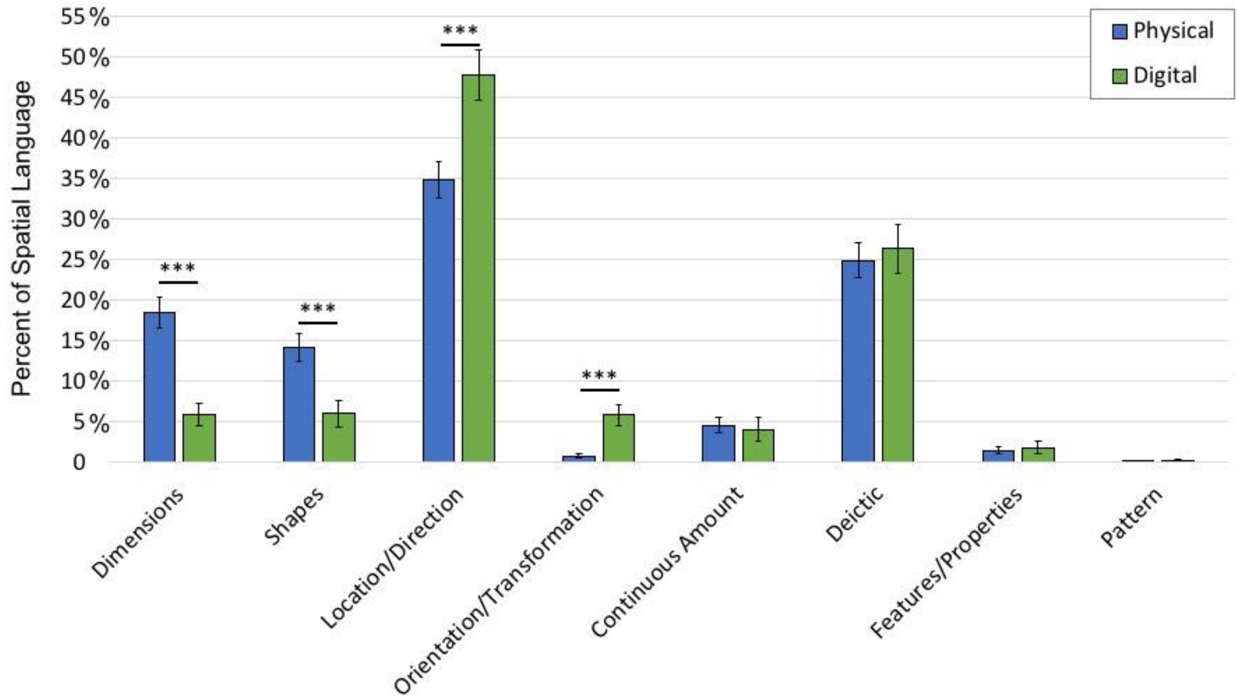

Figure 6. Children's spatial categories by context. Bars represent standard error. *** $p \leq .001$.

Comparison Between 2D and 3D Play Activities. The four activities (puzzles, blocks, *Dragon Shapes*, and *Minecraft*) differed not only in the context of the play – whether presented in a physical or digital format – but also in their dimensions. As noted previously, the puzzles and *Dragon Shapes* activities required dyads to place flat puzzle pieces on a 2D surface; in contrast, the blocks and *Minecraft* activities required dyads to move 3D blocks on a plane. To explore how mothers' and children's spatial words might change based on the activity, two-way ANCOVAs were conducted with play context (physical, digital) and activity dimension (2D, 3D) as within-subjects variables and children's verbal ability as a covariate.

For mothers, there was an interaction between context and dimension, $F(1, 57) = 8.08$, $p = .006$, $\eta_{p2} = .124$, a main effect of context, $F(1, 57) = 5.12$, $p = .027$, $\eta_{p2} = .082$, and a main effect of dimension, $F(1, 57) = 8.11$, $p = .006$, $\eta_{p2} = .125$. With physical play, mothers used more spatial words during the 2D puzzle activity than during the 3D block activity, M_{diff} = 24.12, 95% CI [17.08, 31.16], $p < .001$. They also used more spatial words during the physical puzzle activity than during the digital puzzle (*Dragon Shapes*) activity, M_{diff} = 24.39, 95% CI [18.78, 30.00], $p < .001$; see Table 4 and Figure 7. For children, there was a main effect of context, $F(1, 57) = 6.21$, $p = .016$, $\eta_p^2 = .098$, a main effect of dimension, $F(1, 57) = 9.48$, $p = .003$, $\eta_p^2 = .143$, but no interaction effect, $F(1, 57) = 0.22$, $p = .638$, $\eta_p^2 = .004$. Children used more spatial words during the 3D activities than during the 2D activities, M_{diff} = 2.92, 95% CI [1.27, 4.56], $p = .001$; see Figure 8.

Table 4

Means and Standard Deviations for Mother and Child Language by Activity

	Puzzle	Block	*Dragon Shapes*	*Minecraft*
	M (SD)	M (SD)	M (SD)	M (SD)
Mother				
Total Words	438.20 (157.02)	304.42 (136.80)	221.27 (146.32)	332.95 (130.03)
Non-spatial Words	394.36 (137.01)	282.90 (125.92)	202.07 (131.60)	310.65 (121.32)
Spatial Words	43.85 (24.79)	19.52 (14.16)	19.20 (18.38)	22.30 (12.57)
Child				
Total Words	130.97 (94.27)	208.92 (99.58)	51.52 (56.93)	132.52 (79.99)
Non-spatial Words	120.03 (87.33)	197.35 (93.78)	48.20 (52.79)	123.95 (75.97)
Spatial Words	10.93 (8.87)	11.57 (7.12)	3.32 (5.25)	8.57 (7.03)

Note. Average app language during *Dragon Shapes* included 169.70 total words (*SD* = 26.15), 139.63 non-spatial words (*SD* = 22.98), and 30.07 spatial words (*SD* = 5.45).

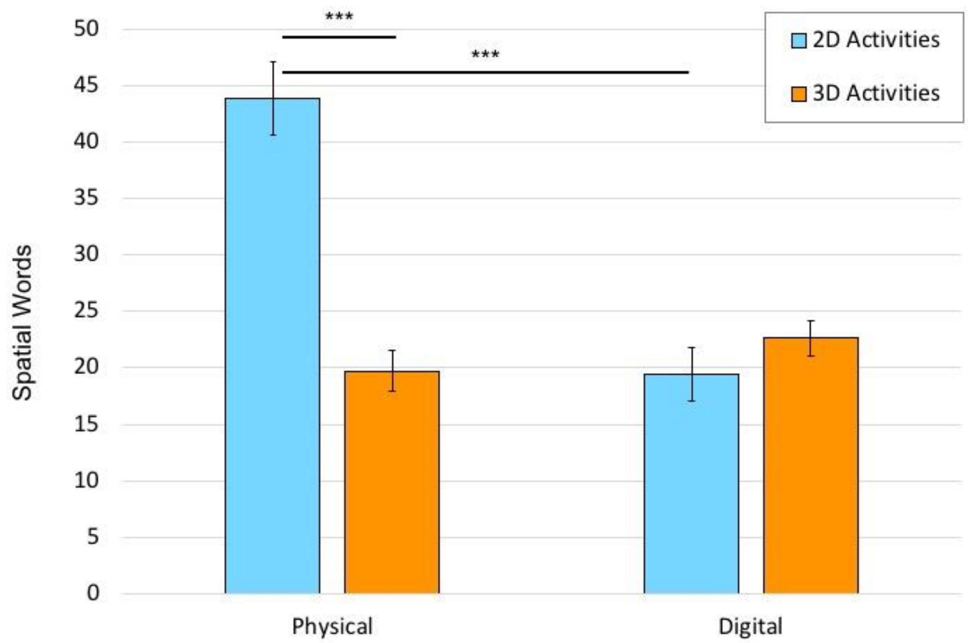

Figure 7. Mothers' spatial words by dimension. Bars represent standard error. *** $p \leq .001$.

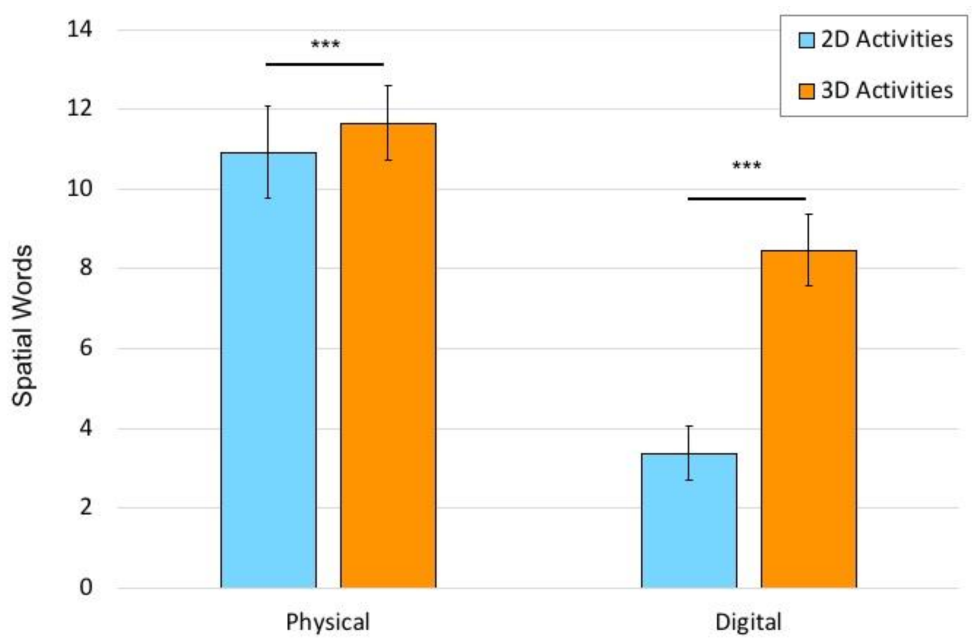

Figure 8. Children's spatial words by dimension. Bars represent standard error. *** $p \leq .001$.

Maternal Questions During Physical and Digital Spatial Play

Descriptives for mothers' questions are displayed in Table 5. Mothers' total words correlated with their total questions, $r(58) = .41$, $p = .001$, and each question type (all Pearson's rs $\geq .28$). Children's total words negatively correlated with mothers' rhetorical questions, $r(58) = -.31$, $p = .018$.

Table 5

Means and Standard Deviations of Maternal Questions

	Total	Physical	Digital
Total Questions	57.48 (22.80)	34.58 (14.08)	22.90 (12.27)
Pedagogical Questions	7.00 (5.31)	4.68 (3.57)	2.32 (3.31)
Generic	1.35 (1.79)	0.97 (1.47)	0.40 (0.83)
Specific	5.63 (5.28)	3.76 (3.62)	1.92 (3.10)
Info-Seeking Questions	36.92 (17.14)	22.03 (11.17)	14.88 (8.38)
Specific	13.63 (7.66)	8.03 (5.52)	5.73 (4.82)
Check Status	12.67 (6.12)	7.29 (3.78)	5.43 (3.51)
Clarification	6.83 (6.84)	4.63 (4.97)	2.28 (2.48)
Permission	3.92 (3.45)	2.56 (2.42)	1.40 (1.76)
Rhetorical Questions	13.57 (8.03)	7.87 (4.53)	5.70 (4.67)
Commands	4.67 (3.81)	2.29 (2.01)	2.37 (2.56)
Attention	8.92 (5.70)	5.68 (3.92)	3.33 (2.94)

Differences in mothers' questions during play were tested with two-way mixed ANOVAs, with child gender as the between-subjects variable and play context (physical, digital) as the within-subjects variable. For mothers' total questions, there was a main effect of context, $F(1, 58) = 49.31$, $p < .001$, $\eta_{p2} = .459$, and an interaction between gender and context, $F(1, 58) = 5.17$, $p = .027$, $\eta_{p2} = .082$, but no main effect of gender, $F(1, 58) = 2.27$, $p = .138$, $\eta_{p2} = .038$. Mothers asked more questions during physical play than during digital play with both female, $F(1, 29) = 10.73$, $p = .003$, $\eta_{p2} = .270$, and male children, $F(1, 29) = 45.49$, $p < .001$, $\eta_{p2} = .611$.

Mothers also asked more questions to male children than female children during physical play, $F(1, 58) = 5.42$, $p = .023$, $\eta_{p2} = .086$, but not during digital play, $F(1, 58) = 0.04$, $p = .852$, $\eta_{p2} = .001$; see Figure 9.

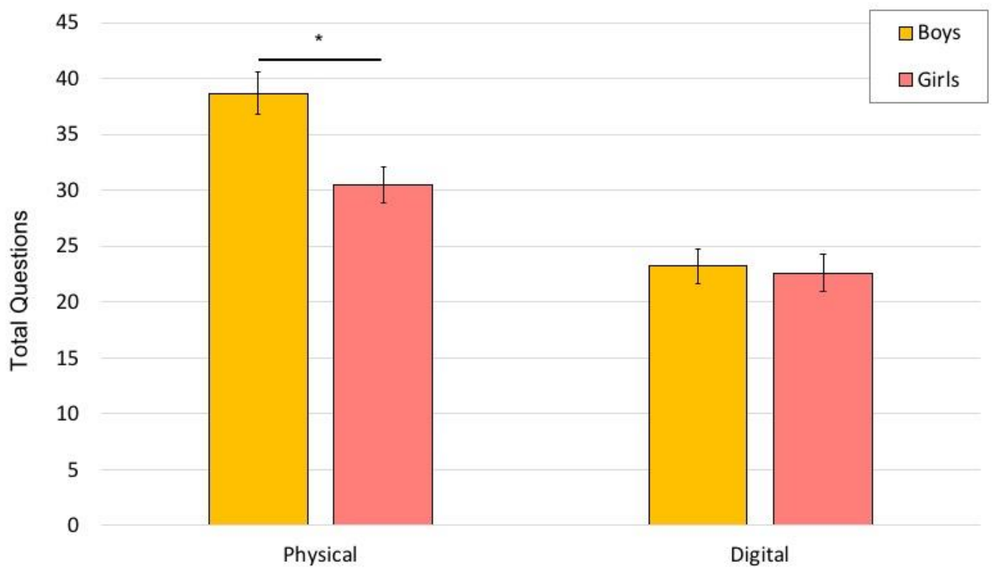

Figure 9. Mothers' total questions by gender. Bars represent standard error. * $p \leq .05$.

Mothers asked more of each question type during physical play than during digital play: pedagogical, $F(1, 58) = 17.16$, $p < .001$, $\eta_{p2} = .228$; information-seeking, $F(1, 58) = 35.35$, $p < .001$, $\eta_{p2} = .379$; rhetorical, $F(1, 58) = 13.69$, $p < .001$, $\eta_{p2} = .191$; see Figure 10. There was no main effect of gender for any of the question types (all *p*s $\geq .161$) but there was a significant interaction between context and gender for information-seeking questions, $F(1, 58) = 7.76$, $p = .007$, $\eta_{p2} = .118$. Post hoc analyses using the Bonferroni adjustment revealed that mothers asked marginally more information-seeking questions to male children ($M = 24.80$, $SE = 1.99$) than to female children ($M = 19.27$, $SE = 1.99$) during physical play, $M_{diff} = 5.53$, 95% CI [-0.11, 11.18], $p = .054$.

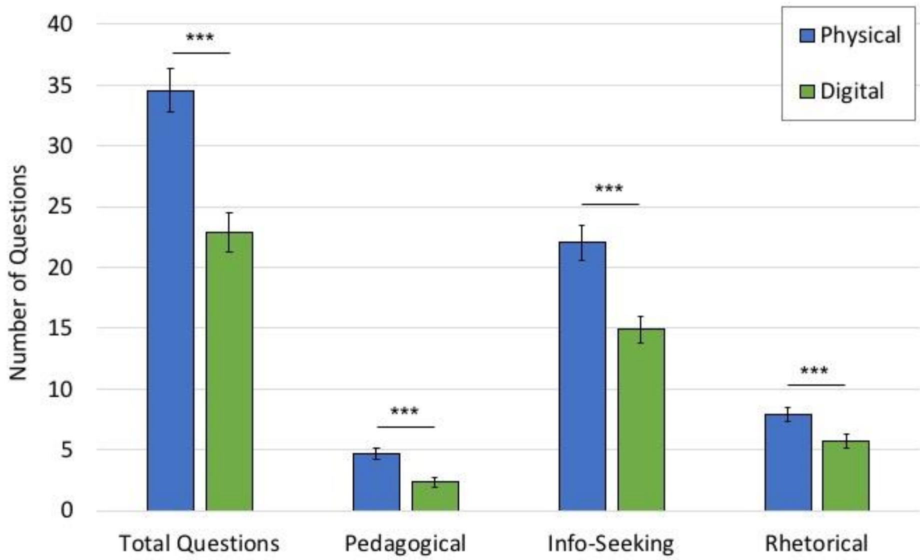

Figure 10. Mothers' question types by play context. Bars represent standard error. *** $p \leq .001$.

Looking specifically at question subcategories, mothers asked significantly more questions during physical play for each subcategory except rhetorical command questions: pedagogical generic, $F(1, 58) = 7.27$, $p = .009$, $\eta_p^2 = .111$; pedagogical specific, $F(1, 58) = 10.99$, $p = .002$, $\eta_p^2 = .159$; information-seeking specific, $F(1, 58) = 6.31$, $p = .015$, $\eta_p^2 = .098$; information-seeking check status, $F(1, 58) = 12.10$, $p = .001$, $\eta_p^2 = .173$; information-seeking clarification, $F(1, 58) = 20.92$, $p < .001$, $\eta_p^2 = .265$; information-seeking permission, $F(1, 58) = 13.28$, $p = .001$, $\eta_p^2 = .186$; rhetorical commands, $F(1, 58) = 0.04$, $p = .841$, $\eta_p^2 = .001$; rhetorical attention, $F(1, 58) = 18.92$, $p < .001$, $\eta_p^2 = .246$; see Figure 11. There was no main effect of gender for any of the question subcategories (all *p*s $\geq .081$) but there was a significant interaction between context and gender for the subcategories of information-seeking specific questions, $F(1, 58) = 7.74$, $p = .007$, $\eta_p^2 = .118$, and information-seeking permission questions, $F(1, 58) = 4.50$, $p = .038$, $\eta_p^2 = .072$. Post hoc analyses using the Bonferroni adjustment revealed that mothers directed more information-seeking specific questions, M_{diff} = 3.60, 95% CI [0.86, 6.34], p = .011, and marginally more information-seeking permission questions, M_{diff} = 1.10, 95% CI [-0.13, 2.33], p = .078, towards male children than female children during physical play.

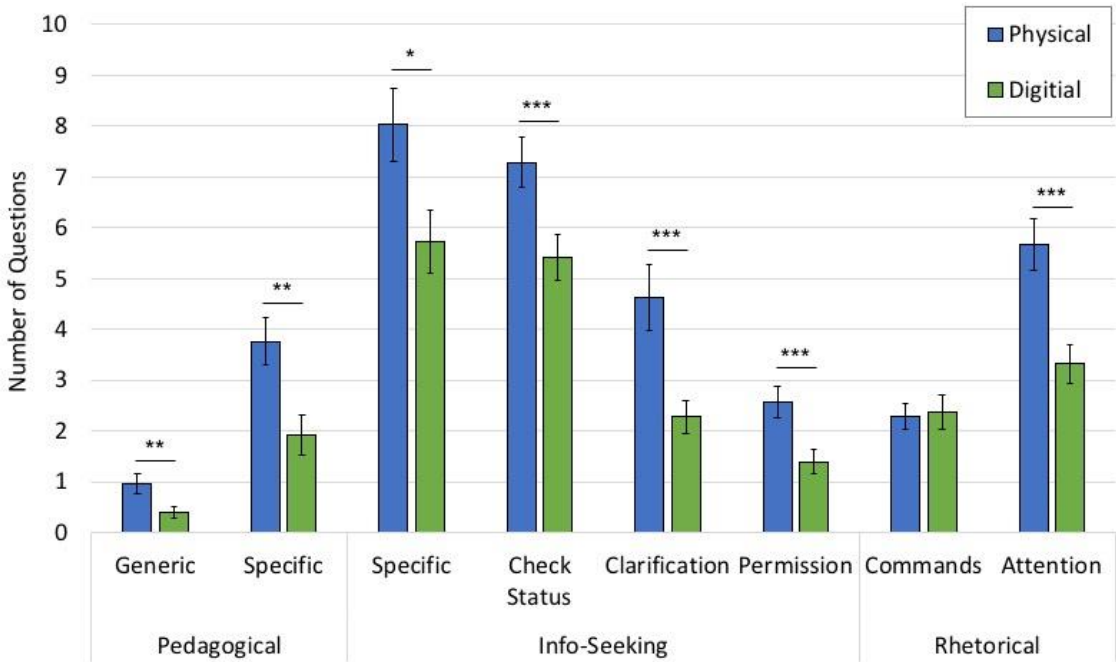

Figure 11. Mothers' question subcategories by play context. Bars represent standard error. * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$.

Comparison Between 2D and 3D Play Activities. To explore how mothers' question-asking might change based on the activity, a two-way ANOVA was conducted on mothers' total questions, with play context (physical, digital) and activity dimension (2D, 3D) as within-subjects variables. This demonstrated a main effect of context, $F(1, 58) = 46.90$, $p < .001$, η_{p2} = .447, main effect of dimension, $F(1, 58) = 73.51$, $p < .001$, η_{p2} = .559, and an interaction between context and dimension, $F(1, 58) = 16.31$, $p < .001$, η_{p2} = .220. Mothers asked more questions during the 3D activity than during the 2D activity for both physical play, M_{diff} = 4.70, 95% CI

[2.77, 6.62], $p < .001$, and digital play, $M_{diff} = 9.88$, 95% CI [7.56, 12.20], $p < .001$; see Figure 12.

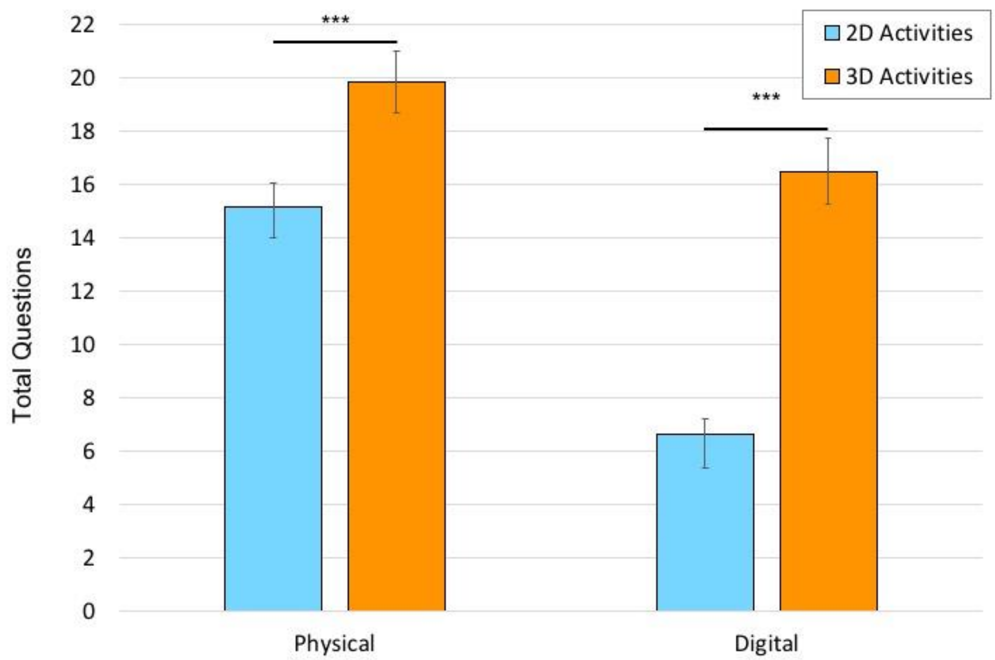

Figure 12. Mothers' total questions by dimension. Bars represent standard error. *** $p \leq .001$.

Parent Questionnaire

Mothers reported their children played with spatial toys on average once a week (M = 3.68, SD = 1.04). Their median responses showed that children played with blocks and building toys several times a week and puzzles once a week. They also reported their children used screen media on average once a week (M = 3.46, SD = 1.14), with median responses showing television use once a day, tablet and smartphone use several times a week, and computer use once a month or less. Mothers also reported their children's weekly screen media use; overall, children spent an average of 6.88 hours each week across all screen media. They spent the most time watching television (4.28 hours a week), as well as a sizeable amount of time using smartphones and tablets (2.45 hours a week), but spent much less time using computers (0.46 hours a week). When asked about the educational value of different activities, mothers rated spatial play highly at 8.48 on the 10-point scale (*SD* = 1.33) but rated screen media at 4.51 (*SD* = 2.17). A paired-samples t-test indicated a significant difference between their ratings, $t(59) = 12.32$, $p < .001$.

Mothers also reported the frequency of their children's play with the specific activities of this study. For the *Minecraft* app, 14 children had played it before and 46 children had never played it. In contrast, no children had previously played the *Dragon Shapes* app. Only 3 children had previously played with physical *Minecraft* blocks, but 26 children had previously played with tangram puzzles (though none with the version designed for this study).

Pearson's correlations indicated no relations between children's frequency of use with spatial toys or screen media and mothers' or children's spatial words, or between children's frequency of use and mothers' questions. Looking specifically at children's prior experience with the activities in the study, only experience with *Minecraft* was related to mothers' spatial words during *Minecraft*, $r(58) = -.31$, $p = .016$. Mothers used fewer spatial words when their children had previous experience with *Minecraft*. For all other activities, there was no relation between children's prior experience and mothers' or children's spatial language.

Discussion

As hypothesized, both mothers and children spoke more spatial words and non-spatial words during physical play than during digital play. During physical play, mothers used more spatial words relating to object dimensions and shapes, but during digital play, they used more spatial words relating to location and direction, orientation and transformation of objects, and deictic words like "here" and "where." Children similarly used more spatial words related to dimensions and shapes during physical play and more spatial words related to location/direction and orientation/transformation during digital play.

Mothers and children both differed in their spatial language based on the dimensions of the activities. Mothers spoke more spatial words during play with the 2D physical puzzles than with the 3D physical blocks and the 2D digital *Dragon Shapes*. In contrast, children spoke more spatial words during play with both 3D activities (blocks and *Minecraft*) than with the 2D activities (puzzles and *Dragon Shapes*). The dimensionality of each activity was an exploratory aspect of this study and it is interesting to note that mothers used the most spatial language during the puzzle activity, whereas children used more spatial language during both block play and *Minecraft*. This may have been due to differences in how the 2D and 3D activities were structured, a point I will return to in the General Discussion.

In addition to their spatial and non-spatial language, mothers also differed across contexts in the questions they asked. They asked more questions overall during physical play than during digital play, which was consistent for each question type (pedagogical, information-seeking, rhetorical). Moreover, for each of the question subtypes except for rhetorical command questions (e.g., “Can you put that down?”), mothers asked them more frequently during physical play. Gender impacted question-asking: Mothers asked more questions of male children than female children during physical play. But this effect was driven by two subcategories of information-seeking questions: specific (e.g., “What are you building?”) and permission (e.g., “Can I help?”) questions. One possibility is that boys took charge of the physical activities more so than girls, leading mothers to ask more specific questions about what was being built and how they could help; such behavior was observed anecdotally and future coding should systematically explore this possibility. This finding and the otherwise absence of gender differences in mothers' and children's language is discussed further in the General Discussion.

To provide context for children's play and media use at home, mothers reported their children's frequency of play with several examples of spatial toys and screen media. Children played with spatial toys and used screen media fairly often (once a week) but mothers viewed their educational value to be quite different, rating spatial toys as almost twice as educational as screen media. This finding aligns with a similar study in which parents reported spatial and non-spatial toys as high in educational value but screen media as only average (Eisen, Matthews, & Jirout, under review). A quarter of the children had played *Minecraft* before, and almost half had played with tangram puzzles, but very few had played with physical *Minecraft* blocks and none had played *Dragon Shapes*. The only activity for which prior experience mattered was *Minecraft*; children who had played *Minecraft* before heard fewer spatial words from their mothers during that activity. This could be because children experienced with *Minecraft* required less support from their mothers during play.

Study 1 revealed that mothers and children behave differently when engaged together in play with physical and digital spatial games. They speak more overall and use more spatial language while playing with physical games, and their spatial language focuses on the dimensions and shapes of the objects they are using. Mothers direct more questions to their children during physical play, including pedagogical questions that can promote children's exploration and learning (Yu, Landrum, et al., 2018). Yet during digital play, mothers and children also use spatial language, particularly to describe the location and direction of objects, or how to orient and transform them. These findings offer insight into mother-child playful interactions that could inform how physical and digital materials are designed to promote learning and engagement.

Chapter 3 - Study Two

Study 1 demonstrated that mothers and children behave differently during play with physical and digital spatial toys. Although descriptive of natural parent-child interactions during play, this study does not offer evidence for the causal impact of spatial play on children's spatial development. Therefore, Study 2 was designed to address two main questions:

1) Does spatial play improve children's spatial skills?
2) Does the impact of spatial play on spatial skills vary for physical versus digital objects?

Children in kindergarten and first-grade classrooms participated in a three-week spatial play intervention, during which they were randomly assigned to play with physical spatial, digital spatial, or non-spatial toys and games for one hour twice a week. Children's spatial reasoning skills were measured before and after the program to assess change, and verbal ability and executive function were measured after the program as control variables.

Based on prior literature suggesting spatial play is causally related to spatial reasoning (e.g., Casey et al., 2008; De Lisi & Wolford, 2002; Yang & Chen, 2010), children in both the physical spatial and digital spatial conditions were expected to improve in their spatial reasoning compared to the control condition. However, because physical spatial play allows children to manipulate real objects in the environment, and based on research comparing learning from physical and digital books and toys, the physical spatial play condition was expected to show the strongest effects on spatial reasoning.

Method

Participants

Fifty kindergarten and first-grade children (26 female) participated, with 15 five-year-olds (M = 68.43, SD = 2.52), 21 six-year-olds (M = 77.32, SD = 3.32), and 14 seven-year-olds (M = 88.41 months, SD = 2.04 months). This age range was chosen because of its use in similar prior research (Casey et al., 2008). Children were placed in conditions using stratified random assignment, such that each condition contained relatively equal numbers of male and female children and of each of the age groups: physical spatial (N = 16, 8 female), digital spatial (N = 17, 8 female), and non-spatial (N = 17, 10 female). An additional child participated in the physical spatial condition but was excluded because he was absent for half of the sessions. An a priori power analysis was conducted using G*Power 3 (Faul et al., 2007), which indicated that 72 participants were sufficient to achieve 95% power using a two-tailed test with a medium effect size (Hedge's g = 0.47), as has been shown in a meta-analysis examining the effects of spatial training (Uttal et al., 2013). However, only 50 children were able to be tested for this study. Children were recruited from kindergarten and first-grade classrooms at two local elementary schools: 16 children were from School A and 34 children were from School B. At School A, 23% of the students identify as Black/African-American, 23% identify as Hispanic/Latino, and 36% identify as White; additionally, 55% of students receive free and reduced lunch. At School B, we were given demographic information specific to kindergarten students: 24% identify as Black/African-American, 28% identify as Hispanic/Latino, 29% identify as White, 12% identify as Asian, and 7% identify as multiracial. Parents provided written consent and children verbally agreed to participate, in line with the study's approval from the university's Institutional Review Board.

Measures

Spatial Measures. Children's spatial reasoning skills were measured before and after the intervention with three tests that assessed mental transformation, spatial scaling, and spatial visualization.

***Mental Transformation*.** Mental transformation was measured using the Children's Mental Transformation Task (CMTT; Levine et al., 1999), in which children indicate which of four shapes would be made from moving two separate pieces together. The full measure includes 32 items but a shortened 16-item version was used here. The CMTT has previously been correlated with children's puzzle play (Levine et al., 2012).

***Spatial Scaling*.** Spatial scaling was measured using a paper version of a spatial scaling task developed for 5- to 10-year-olds (Gilligan et al., 2018), in which children use information from a spatial representation (a map) to choose the same location (out of four possibilities) shown by a smaller scaled representation. The measure includes 18 items worth one point each. Spatial scaling has previously been studied as a visuospatial task that is akin to the "real-life" skill of map reading and fits within the realm of spatial-relational reasoning (Frick & Newcombe, 2012; Jirout & Newcombe, 2014; Verdine et al., 2008).

***Spatial Visualization*.** Spatial visualization was measured using the WPPSI-IV Block Design task (Wechsler, 2012). As described in Study 1, the Block Design task is often used to measure children's general spatial ability, but it also serves as a measure of spatial visualization (Groth-Marnat & Teal, 2000) and was used in this capacity in Study 2. Scores ranged from 0 to 34.

Control Measures. Children were measured after the intervention on executive function and verbal ability to control for their associations with spatial reasoning (Verdine et al., 2017).

Executive Function. Executive function was measured with Head-Toes-Knees-Shoulders (McClelland et al., 2007; Ponitz et al., 2008), a task in which children must do the opposite of what an experimenter says (e.g., touch head when experimenter says to touch toes). Scores ranged from 0 to 60.

Verbal Ability. Verbal ability was measured using the Receptive Vocabulary subtest of the WPPSI-IV (Wechsler, 2012), which assesses verbal comprehension by asking children to select the picture that best represents a word read aloud by the experimenter. Scores ranged from 0 to 31.

Materials and Procedure

The play intervention was conducted in two rounds. The first round took place in April 2019 with kindergarten and first-grade students at School A during their class time and at School B during an after-school program. The second round took place in February 2020 in a single kindergarten classroom at School B. I will first describe the general procedure and the materials used for the intervention. Then, I will detail aspects of the procedure that differed between the two rounds of the intervention.

The intervention took place across a three-week period, with two days each week that contained an hour-long session (6 hours total; see Figure 13). Before the first day of the intervention, children were tested on the spatial reasoning measures by undergraduate and graduate researchers who were not otherwise associated with the intervention and did not know the hypotheses, conditions, or other details of the study. After the sixth and final day of the intervention, children were again tested on the same spatial reasoning measures and were also tested on the control measures. The post-test researchers were largely the same as the pre-test researchers but were assigned to test different children at post-test to avoid potential bias from having observed children's performance at pre-test.

	Monday	Tuesday	Wednesday	Thursday	Friday
Pre-test			Pre-test		
Week 1	Session 1		Session 2		
Week 2	Session 3		Session 4		
Week 3	Session 5		Session 6		
Post-test	Post-test				

Figure 13. Example intervention calendar.

For the intervention, children were grouped by condition and seated separately from other conditions. To help easily identify children, they wore aprons painted with colors to represent their conditions. Physical spatial and non-spatial participants were positioned in different areas of the same large room, and digital participants were placed in a separate room due to concerns that their materials might distract the other children. Each group contained 5 or 6 children led by a hypothesis-blind undergraduate research assistant (hereafter referred to as a facilitator). Children remained in their assigned conditions throughout the study, but facilitators led a different condition each day, so that each facilitator ultimately led two physical, two digital, and two non-spatial groups across the full intervention. This strategy was chosen to avoid potentially confounding condition effects with experimenter effects. As the lead experimenter, I supervised all sessions but was not a facilitator. However, out of necessity, I replaced an absent facilitator for the last two sessions of round 2.

Each session followed a consistent schedule (see Figure 14). The facilitators used the first five minutes to set up and explain the activities, and then facilitators and children engaged together in the first activity for twenty minutes. Next, there was a five minute period for them to clean up the first activity and set up the second activity, followed by twenty minutes of play with the second activity. The session ended with approximately ten minutes to clean up the second activity and return children to their classrooms. Sessions were video recorded, with two cameras placed at each table for round 1 and one camera at each table for round 2. The cameras were positioned to provide a full view of the children and play materials. Videos were not analyzed for this study but offer rich data for future exploration, which will be considered in the discussion.

Figure 14. Daily session schedule.

The activities were chosen to provide a range of play within the parameters of each condition. For each session, the first activity involved a toy that could be played with individually or in pairs or small groups, depending on children's preferences. The second activity was a board game to be played in either pairs or small groups. The full list of activities and their order in the intervention is provided in Table 6.

Table 6

Schedule of Intervention Activities

Day 1 – Puzzles			Day 2 – Blocks		
Physical	Tangrams	Connect 4	**Physical**	Blocks	Jenga
Digital	Dragon Shapes	Connect 4	**Digital**	Minecraft	Balanced Tower
Non-spatial	Coloring	Scrabble Jr.	**Non-spatial**	Magnets	Hi Ho! Cherry-O
Day 3 – Gears			**Day 4 – Puzzles**		
Physical	Gears	Rush Hour Jr.	**Physical**	Tangrams	Chutes and Ladders
Digital	Crazy Gears	Unblock My Car	**Digital**	Dragon Shapes	Snakes and Ladders
Non-spatial	Fishing	Lion In My Way	**Non-spatial**	Coloring	Candy Land
Day 5 – Blocks			**Day 6 – Gears**		
Physical	Blocks	Set Jr.	**Physical**	Gears	Thinking Putty Puzzle
Digital	Minecraft	Set	**Digital**	Crazy Gears	Flow Free
Non-spatial	Magnets	Spot It Jr.	**Non-spatial**	Fishing	Silly Putty

Physical Spatial Materials. The physical spatial toys were the *Minecraft* blocks and tangram puzzles from Study 1 and *Learning Resources* plastic gears. Each toy was given to children twice during the intervention. Children were given individual materials but could choose to play together. The physical spatial board games were *Jenga*, *Connect 4*, *Rush Hour Jr.*, *Set Jr.*, *Chutes and Ladders*, and *Crazy Aaron's Thinking Putty Puzzle*. Each board game was given to children once during the intervention. Children played the board games in pairs or groups of three, depending on the particular game and the size of the group. The physical spatial materials were chosen based on past research showing play with blocks, puzzles, and board games relates to children's spatial abilities (Jirout & Newcombe, 2015).

Digital Spatial Materials. The digital spatial materials were apps presented on iPads (iPad Air, 1st generation). The apps were *Minecraft*, *Dragon Shapes – Lumio Geometry Challenge*, *Crazy Gears*, *Balanced Tower*, *Connect 4*, *Unblock My Car*, *Set*, *Snakes and Ladders*, and *Flow Free*. Each app was chosen to be comparable to the physical spatial materials. *Minecraft*, *Dragon Shapes*, and *Crazy Gears* were given to children twice during the intervention and all other apps were given to children once; see Table 6. For *Minecraft*, *Dragon Shapes*, and *Crazy Gears,* children played individually on their own iPads. For *Balanced Tower*, *Connect 4*, *Unblock My Car*, *Set*, *Snakes and Ladders*, and *Flow Free*, children were paired to play together on an iPad in order to match the activities more closely to their physical counterparts. iPads were kept in the Guided Access setting, which restricts users from leaving a particular app; this kept children from attempting to play games other than the one the facilitator intended.

Non-spatial Materials. The non-spatial materials were chosen as activities that did not necessitate spatial reasoning but were comparable to the physical and digital spatial activities in length of time and level of engagement. It should be noted that most play contains spatial elements, so non-spatial toys were characterized as ones that do not require children to actively attend to spatial relations while playing. The non-spatial toys were *Learning Resources Super Magnet Lab Kits*, coloring pages along with the children's book *Dragons Love Tacos*, and a fishing game designed by the experimenter. For the magnet activity, children were given a magnet wand, several smaller magnets, and a pile of magnetic bingo chips. The facilitator encouraged children to experiment with the magnets. For the coloring activity, children were given an assortment of dragon-themed coloring pages and a set of crayons and were invited to color while the facilitator read the book. For the fishing game, children were given toy fishing rods and they "fished" for laminated multi-colored paper fish. The facilitator gave children goals such as “Get all the blue fish” or “Get a fish of each color.” Each of these activities was given to children twice during the intervention. The activities were designed to be played individually

The non-spatial board games were *Hi Ho! Cherry-O*, *Scrabble Jr.*, *Lion In My Way*, *Spot It Jr.*, *Candy Land*, and *Silly Putty*. *Silly Putty*, while not technically a board game, was chosen because it was comparable to *Crazy Aaron’s Thinking Putty Puzzle* but did not require placing putty in particular configurations on a board. Instead, the facilitator encouraged children to be creative in how they used the putty. Each board game was given to children once during the intervention. Children played the board games in pairs or groups of three, depending on the particular game and the size of the group.

Changes in Procedure Between Rounds. For round 1, children from School 1 were in mixed-age classrooms with kindergarten, first-grade, and second-grade students taught together, and children from School 2 were in a mixed-age after-school program with kindergarten and first-grade students. Participants in the study were pulled out of class or the after-school program and brought to separate rooms for the intervention.

For round 2, children were all part of a single kindergarten classroom at School 2. The entire class (35 children) took part in the play intervention but only 21 children were participants in the study. For those children, pre-testing occurred across two days before the start of the intervention and post-testing for two days after the intervention was complete. Participants were randomly assigned to conditions first, then non-participants were also randomly assigned until each condition was the same size and held roughly equal numbers of boys and girls. The intervention took place during class time and followed the same general schedule as the previous round (see Table 6). Because the number of children participating at one time was more than doubled, the conditions were also doubled so that there were two physical spatial, two digital spatial, and two non-spatial conditions. Each condition had a facilitator (6 total) who rotated between conditions for each session in the same way as round 1. The physical spatial and non-spatial conditions were seated at four separate tables in the classroom; one of the digital spatial conditions was seated at a table just outside the classroom and the other was seated in a separate room down the hall. To avoid purchasing double the play materials, the conditions were staggered in their order of materials (see Appendix E). For example, on the first day of the intervention, one of the physical spatial conditions played with *Minecraft* blocks and *Jenga*, while the other played with *Learning Resources* plastic gears and *Rush Hour Jr*. The digital spatial conditions were also staggered in this manner but extra iPads were acquired so that each child had their own.

Parent Questionnaire

Parents completed a questionnaire that was adapted from the questionnaire used in Study 1. First, parents were asked about the frequency of their children's exposure to spatial toys (blocks, puzzles, building toys), non-spatial toys (books, dolls/stuffed animals, balls, outside play, drawing materials), and screen media (television, computers, tablets/smartphones) on a 6-point scale ranging from "several times a day" to "once a month or less." Parents were also asked how important they considered each of the play activities listed above for learning on a 10-point scale from "not important" to "extremely important." Next, parents reported how many and the types of televisions, computers, smartphones, and tablets present in their homes, as well as the minutes per week their children used each. Finally, for each game, toy, and app used in the study, parents reported if their children had ever played with it in either physical or digital form, and the minutes per week their children played with it (see Appendix F for full questionnaire).

Results

Descriptives and Correlations

Preliminary analyses examined relations among spatial variables (mental transformation, spatial scaling, spatial visualization) and control variables (verbal ability, executive function, age); see Table 7 for descriptives. There was a positive correlation between pre- and post-test scores for mental transformation, $r(50) = .74$, $p < .001$, spatial scaling, $r(50) = .56$, $p < .001$, and spatial visualization, $r(50) = .66$, $p < .001$. Therefore, further correlations considered post-test scores only. The spatial measures were positively correlated with each other: mental transformation and spatial scaling, $r(50) = .43$, $p = .002$, mental transformation and spatial visualization, $r(50) = .53$, $p < .001$, spatial scaling and spatial visualization, $r(50) = .63$, $p < .001$. Children's verbal ability was correlated with the three outcome measures: mental transformation, $r(50) = .54$, $p < .001$, spatial scaling, $r(50) = .31$, $p = .028$, and spatial visualization, $r(50) = .38$, $p = .007$. Executive function was also correlated with mental transformation, $r(50) = .47$, $p = .001$, spatial scaling, $r(50) = .52$, $p < .001$, and spatial visualization, $r(50) = .59$, $p < .001$. Age was related to all spatial and control measures (all Pearson's rs $\geq .32$); see Appendix G for correlation table. Verbal ability, executive function, and age were controlled for in the following analyses.

Table 7

Means and Standard Deviations of Spatial and Control Measures

	Physical (n = 16)		Digital (n = 17)		Non-spatial (n = 17)	
	M (SD)	Range	M (SD)	Range	M (SD)	Range
Mental transformation						
Pre	9.94 (2.89)	4-15	9.71 (3.80)	0-15	9.53 (3.36)	3-15
Post	10.44 (3.39)	3-15	10.65 (3.10)	3-16	10.29 (3.98)	2-16
Spatial scaling						
Pre	8.56 (2.45)	5-13	9.65 (2.47)	4-14	9.47 (2.76)	5-14
Post	9.88 (4.00)	5-16	9.76 (2.75)	5-15	9.76 (2.73)	5-15
Spatial visualization						
Pre	22.06 (4.54)	15-30	22.47 (4.67)	16-32	23.71 (4.18)	19-32
Post	22.88 (6.31)	10-32	24.59 (4.89)	14-34	24.71 (4.30)	16-30
Verbal ability	23.50 (4.16)	17-30	21.76 (6.82)	3-29	23.06 (4.26)	13-29
Executive function	31.19 (25.67)	0-59	37.24 (18.96)	0-58	34.94 (18.43)	0-59

Spatial Outcomes

For each spatial measure, independent samples t-tests indicated no gender differences for pre-test and post-test scores. Separate repeated-measures ANCOVA tests were conducted for each spatial measure, with condition as the between-subjects variable, time (pre, post) as the within-subjects variable, and verbal ability, executive function, and age as covariates.

For mental transformation, there was no main effect of condition, $F(2, 44) = 0.18$, $p = .840$, $\eta_{p2} = .008$, no main effect of time, $F(1, 44) = 1.16$, $p = .287$, $\eta_{p2} = .026$, and no interaction between them, $F(2, 44) = 0.17$, $p = .846$, $\eta_{p2} = .008$; see Figure 15.

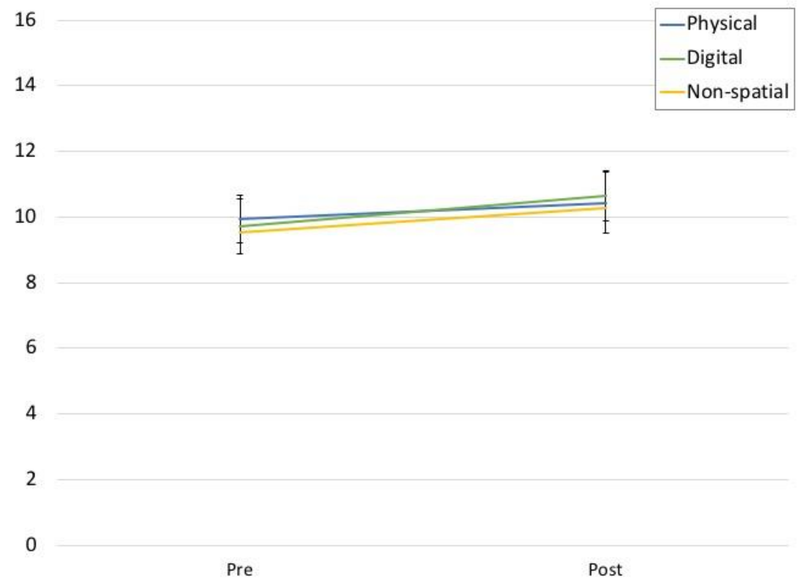

Figure 15. Children's mental transformation scores by condition. Bars represent standard error.

For spatial scaling, there was no main effect of condition, $F(2, 44) = 0.02$, $p = .979$, $\eta_{p2} = .001$, no main effect of time, $F(1, 44) = 0.06$, $p = .803$, $\eta_{p2} = .001$, and no interaction between them, $F(2, 44) = 1.16$, $p = .324$, $\eta_{p2} = .050$; see Figure 16.

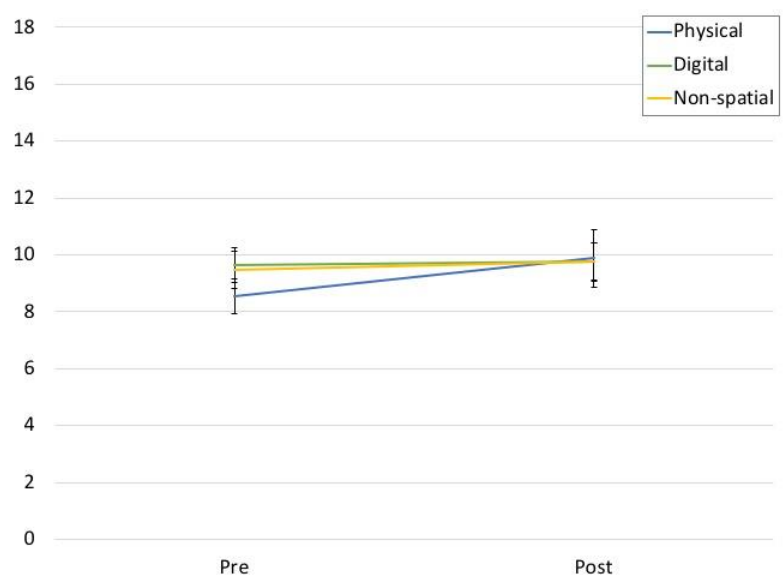

Figure 16. Children's spatial scaling scores by condition. Bars represent standard error.

For spatial visualization, there was no main effect of condition, $F(2, 44) = 0.55$, $p = .583$, $\eta_{p2} = .024$, no main effect of time, $F(1, 44) = 0.12$, $p = .734$, $\eta_{p2} = .003$, and no interaction between them, $F(2, 44) = 0.41$, $p = .670$, $\eta_{p2} = .018$; see Figure 17.

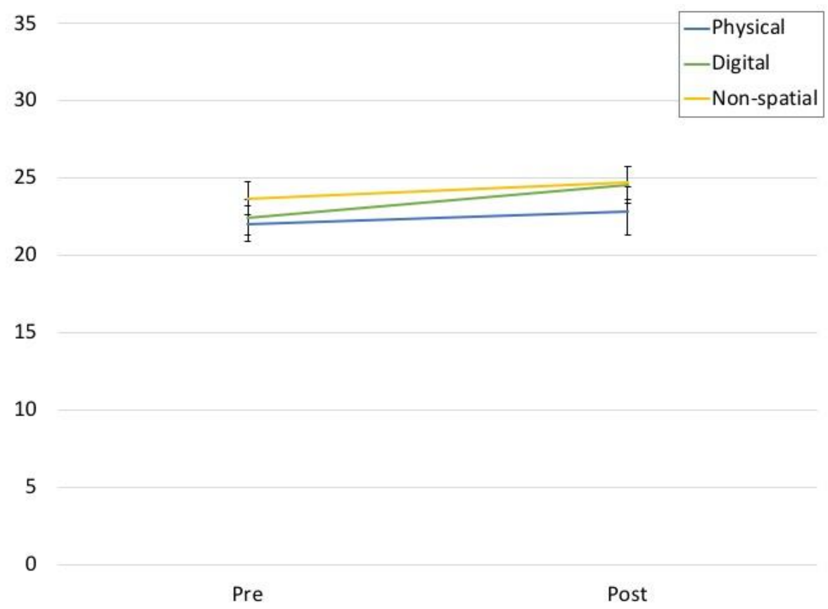

Figure 17. Children's spatial visualization scores by condition. Bars represent standard error.

Comparison of Combined Spatial and Non-spatial Conditions. To test whether the spatial conditions differed from the control condition, the physical and digital conditions were collapsed and compared to the non-spatial condition. Separate repeated-measures ANCOVA tests were conducted for each spatial measure, with condition (spatial, non-spatial) as the between-subjects variable, time as the within-subjects variable, and verbal ability, executive function, and age as covariates. For mental transformation, there was no main effect of condition, $F(1, 45) = 0.28$, $p = .599$, $\eta_{p2} = .006$, no main effect of time, $F(1, 45) = 1.44$, $p = .236$, $\eta_{p2} = .031$, and no interaction between them, $F(1, 45) = 0.001$, $p = .983$, $\eta_{p2} = .001$. For spatial scaling, there was no main effect of condition, $F(1, 45) = 0.03$, $p = .875$, $\eta_p^2 = .001$, no main effect of time, $F(1, 45) = 0.001$, $p = .993$, $\eta_p^2 = .001$, and no interaction between them, $F(1, 45) = 0.24$, $p = .625$, $\eta_p^2 = .005$. For spatial visualization, there was no main effect of condition, $F(1, 45) = 1.03$, $p = .315$, $\eta_p^2 = .022$, no main effect of time, $F(1, 45) = 0.22$, $p = .641$, $\eta_p^2 = .005$, and no interaction between them, $F(1, 45) = 0.20$, $p = .658$, $\eta_p^2 = .004$.

Parent Questionnaire

Approximately half of the questionnaires ($n = 26$) were returned by parents. The questionnaire addressed a wide range of activities but also asked specifically about children's experience with each game, toy, and app used in the study. The analyses here focused only on items related to spatial toys and screen media. For the questions about frequency of play and perceived educational value, responses were averaged to create a category for spatial toys (blocks, puzzles, building toys) and for screen media (television, computers, tablets/smartphones). To calculate children's prior exposure to the study materials, the spatial games, toys, and apps with which they had experience were summed to create a spatial play score. General prior experience (yes or no) was used instead of minutes per week because parents often left that field blank. Similarly, parents sometimes responded for only the physical items or only the digital items, leaving the other portion blank. Thus, both physical and digital spatial games were summed into one spatial play variable so as to maximize the amount of children who could be included in analyses. Here, I report descriptives for the questionnaire and then relations between items on the questionnaire and the outcome measures of the study.

Children played with spatial toys on average once a week ($M = 3.10$, $SD = 0.89$). Median responses showed that children played with blocks several times a month, with puzzles once a week, and with building toys several times a week. Children used screen media on average several times a week (*M* = 4.06, *SD* = 0.82), with median responses showing television, tablet, and smartphone use once a day and computer use several times a month. Mothers also reported their children's weekly screen media use; overall, children spent an average of 9.21 hours each week across all screen media. They spent the most time watching television (4.30 hours a week), as well as a sizeable amount of time using smartphones and tablets (4.57 hours a week), but spent much less time using computers (0.43 hours a week). Paired-samples t-tests indicated a significant difference between children's frequency of use of spatial toys and screen media, $t(21) = -3.88$, $p = .001$. When asked about the educational value of different activities, mothers rated spatial play 7.46 on the 10-point scale (*SD* = 1.33) and rated screen media 4.51 (*SD* = 2.17), $t(24) = 5.25$, $p < .001$. The average spatial play score (i.e., the cumulative number of spatial activities children had previously experienced) was 4.13 (*SD* = 2.13); however, only 15 children had provided data with which to calculate this score.

Pearson's correlations indicated no relations between children's frequency of use with spatial toys or screen media and their mental transformation, spatial scaling, and spatial visualization scores. Similarly, there were no relations between parents' perceptions of educational value for spatial toys or screen media and children's spatial outcomes. Lastly, there were no relations between children's prior experience with the games, toys, and apps in the study and their spatial outcomes.

Discussion

A three-week spatial play intervention with kindergarten and first-grade students demonstrated no effects of physical or digital spatial play on children's spatial reasoning skills. Children who had engaged in spatial play did not show demonstrable changes in their mental transformation, spatial scaling, and spatial visualization between pre-test and post-test. The physical spatial and digital spatial conditions did not differ from the non-spatial control condition, regardless of whether the spatial conditions were considered separately or together. Parents reported their children's prior exposure to the intervention materials but no association was found between prior exposure and the spatial measures.

Why did the spatial play intervention have no effect on children's spatial performance? There are several possible explanations. First, the materials chosen for the intervention may not have fit the intended goals. The physical spatial materials were chosen based on prior studies that show blocks, puzzles, and board games are associated with children's spatial ability (Jirout & Newcombe, 2015; Levine et al., 2012; Verdine et al., 2017), with block building in particular shown to improve children's spatial visualization (Casey et al., 2008). The digital spatial materials were chosen primarily to be comparable to their physical counterparts, but similar digital spatial games have also been shown to improve children's spatial performance (De Lisi & Wolford, 2002; Subrahmanyam & Greenfield, 1994; Yang & Chen, 2010). In contrast, the non-spatial materials were chosen not for particular qualities they held but rather for their lack of "spatial-ness". Superficial aspects of the spatial and non-spatial activities were matched (e.g., the dragon theme of the tangram puzzles, *Dragon Shapes* app, and the coloring activity), but the non-spatial materials were mainly distinguished by their absence of spatial demands. However, some of the non-spatial activities may have required more spatial reasoning than was intended. For example, the fishing game, although arguably less spatial than its equivalent (gears), still required children to perceive the location of the fish and move their fishing rods to capture them. Essentially, all actions require spatial thinking, and children in the non-spatial condition may have also experienced play that promoted their spatial skills. However, one could then expect to see all the conditions improve on the spatial measures; instead, none improved. It therefore seems unlikely that the non-spatial materials, however inadvertently spatial they may be, are at fault.

A second possibility is that the spatial measures were not well-aligned with the spatial play activities. The measures – mental transformation, spatial scaling, and spatial visualization – were chosen as three tests that have been frequently used in other studies examining relations between spatial play and spatial ability (e.g., Casey et al., 2008; Jirout & Newcombe, 2014, 2015; Levine et al., 2012; Verdine et al., 2008). Children were expected to draw on all three skills during their spatial play: completing puzzles required mental transformation to understand how shapes should be put together, building with blocks required spatial visualization to imagine the finished structure, and several of the board games required spatial scaling between scaled down maps and a game board. Still, other spatial measures may have better captured the effects of the play. Mental rotation, for example, is a commonly measured spatial skill in other studies and would be needed for many of the play activities in this study. Spatial working memory was also considered for inclusion in the measures, since some board games required children to remember spatial layouts. Only three spatial measures were included in the present study because of time constraints with pre- and post-testing, but future work could include a battery of spatial measures expected to map on to specific activities in the intervention.

Although the materials and measures used in the intervention may have resulted in the null effects seen in this study, it is more plausible that the issue is the length and frequency of exposure to the intervention. Children participated in the intervention for one hour twice a week for three weeks, resulting in 6 total hours of participation. Of that, as much as two hours may have been spent setting up, transitioning between, or cleaning up the activities. Considering that some intervention studies have seen effects after exposing children to spatial play for as little as one to two hours (Subrahmanyam & Greenfield, 1994; Yang & Chen, 2010), the length of this intervention seemed reasonable during the design stage. However, a longer intervention would have given children in the spatial conditions more opportunities to engage in spatial thinking, which might have translated to better performance at post-test. Casey et al. (2008) enacted their block building intervention over a six to eight week period; ideally, our intervention would have continued for a similar length of time. Notably, their block intervention also used similar materials across the entire period, whereas ours used a wide range of spatial toys and games. It may be that a longer and more concentrated exposure to spatial play would have resulted in tangible effects.

As noted before, the play group facilitators were undergraduate research assistants who were not informed about the hypotheses of the study. They were also not given explicit direction on how they should lead the activities or interact with the children. Instead, they were taught the rules of the games and given general guidance on how to keep children engaged with the activities. In not providing direct instruction to the facilitators, I hoped to foster their natural style of interaction with the children. Some facilitators were very comfortable in their role and could adapt the activity to the needs of the children. Others liked to stick with the rules of activities and would shift children back on track. Some engaged with children throughout the session, regularly asking questions or even playing with the materials themselves, while others took a more supervisory role. These natural variations in facilitator behavior, which have been captured on video, offer rich data for future exploration of how adults and children engage together in physical and digital spatial play.

Study 2 demonstrated that 5- to 7-year-olds' spatial reasoning skills did not change after a three-week spatial play intervention. There was no change in spatial reasoning between pre-test and post-test for either the physical spatial or the digital spatial condition in comparison to the non-spatial control condition. Although this may be due to the specific materials or measures used, the likely explanation is that the intervention was too brief to produce noticeable changes in children's spatial abilities. Yet this study was the first to compare physical and digital spatial play, and with the growing popularity of digital spatial games like *Minecraft*, future research should continue to investigate how children engage in and learn from physical and digital spatial play.

Chapter 4 - General Discussion

The present studies aimed to examine children's physical and digital spatial play in two social/physical settings: mother-child dyads in the laboratory and small groups in the classroom. Each setting offered opportunities for different types of questions. In Study 1, the research questions were descriptive and focused on what differed in mothers' and children's behavior between physical and digital play. Specifically, Study 1 asked:

1) Do mothers use more spatial language during physical or digital spatial play?
2) Do children use more spatial language during physical or digital spatial play?
3) Do mothers ask more questions to their children during physical or digital spatial play?

Although the answers can inform learning, Study 1 did not directly measure children's learning. Thus, Study 2 examined the causal impact of a classroom-based spatial play intervention on children's spatial abilities and asked:

1) Does spatial play improve children's spatial skills?
2) Does the impact of spatial play on spatial skills vary for physical versus digital objects?

In this section, I will first separately discuss the findings of Study 1 and Study 2 and related topics for each. Then I will discuss how adults can support children's spatial development and future directions of this work.

Mother-Child Spatial Play

The results of Study 1 showed that mothers and children demonstrate different behavior across play contexts. During physical spatial play, mothers spoke more overall and used more spatial words, and they more often used spatial words related to object dimensions and shapes. They also asked more questions—pedagogical, information-seeking, and rhetorical—during physical play. However, during digital play, mothers used more spatial words referring to location/direction, orientation/transformation, and deictics. Children also spoke more and used more spatial words during physical spatial play. Like mothers, children used more spatial words referring to dimensions and shapes during physical play, and to location/direction and orientation/transformation (but not deictics) during digital play.

Higher levels of language, including spatial language, were expected during physical play based on past studies of parent-child interactions with physical and digital toys (Sosa, 2016; Verdine et al., 2019; Zosh et al., 2015), and indeed, Study 1 found more overall language and spatial language for mothers and children during physical spatial play. But it should be noted that, as in other studies, one of the digital apps used in this study produced its own language, including spatial words. In fact, the app produced a sizable amount of the spatial words heard during the activity: 62% versus the 32% produced by mothers. Verdine et al. (2019) and Zosh et al. (2015) similarly found that the electronic toys and apps used in their studies produced a substantial portion of the total spatial language. This raises the question of whether language from an app can replace language from a live social partner. A social partner is able to adapt their language to the needs of the child, whereas the *Dragon Shapes* app produced a set script of dialogue. Children who progressed further in the app heard more language from it, but mothers' spatial language was not dependent on children's progress. With this in mind, it seems implausible that the language produced by an app can replace the social contingency of another person, who can tailor their language to fit the unique conversation with a child.

Mothers' question-asking was also expected to be higher during physical play. Other studies have shown that parents and children engage in more content-focused talk during print book reading compared to digital book reading (Chiong et al., 2012; Krcmar & Cingel, 2014; Parish-Morris et al., 2013). Although question-asking is not the same thing as content-focused talk, they may serve similar purposes of focusing the child on the task at hand and maintaining engagement in the activities. In particular, mothers' pedagogical questions could foster children's exploration during the activities, potentially leading to enhanced learning (Yu, Landrum, et al., 2018). Although in this study, mothers asked pedagogical questions twice as often during physical play than digital play, the overall frequency of pedagogical questions was about half what would be expected based on Yu, Bonawitz, and Shafto (2017). This could be because, in contrast to the open-ended conversations between parents and children they considered, here the conversations were based around play activities that may not have been perceived as educational opportunities. On the other hand, mothers might have understood the experimental setting to be an inherently educational one, in which case we could have expected them to ask more pedagogical questions. This issue should be explored further in future studies of question-asking.

Mothers and children showed similar patterns in their use of specific types of spatial language, which may be explained by the materials. During physical play with blocks and tangram puzzles, dyads were provided with all the materials they would need for the duration of each activity. For example, during the puzzle activity, dyads were given 74 puzzle pieces of varying shapes and dimensions and 80 puzzle templates with the necessary pieces described on the back. It therefore makes sense that dyads would discuss shapes and dimensions frequently during the activity as they decided which of the many pieces were correct for a particular puzzle. Conversely, the *Dragon Shapes* app provided dyads with the exact pieces needed for each puzzle, thus prompting less talk about the pieces' shapes and dimensions.

The digital activities may instead have required more discussion of location/direction and orientation/transformation because placing objects in particular positions was more difficult than it would be for physical objects. In both *Minecraft* and *Dragon Shapes*, users must manipulate small virtual objects on a touchscreen. Although dyads playing *Minecraft* did not have to build structures in a specific way, they were given guides to possible structures they could build (see Figure 2). For *Dragon Shapes*, users needed to move shapes into the correct positions to complete the puzzle. Both activities likely encouraged talk around where and how objects should be placed on the digital plane, and *Dragon Shapes* may have especially required words like "rotate" or "spin" to describe how the pieces should be oriented in the puzzle.

Two-Dimensional Versus Three-Dimensional Play

The activities also differed in their dimensionality, with the puzzle and *Dragon Shapes* games using two-dimensional puzzle pieces and the block and *Minecraft* games using three-dimensional blocks. This dimensionality impacted mother-child language: mothers used more spatial words during the 2D puzzles than during the 3D blocks and the 2D *Dragon Shapes*, whereas children used more spatial words during both 3D activities (blocks and *Minecraft*) in comparison to both 2D activities (puzzles and *Dragon Shapes*). Importantly, the activities also differed in how structured they were and this may have affected how dyads engaged. The *Dragon Shapes* app, and thus the physical puzzle created from it, offered a goal structure of completing each puzzle to progress through the game and the story, and the app provided feedback after successful completion of each puzzle in the form of lightning bolts (see Figure 1) and a spoken phrase (e.g., "Triangle training!"). During the comparable puzzle activity, mothers were not specifically told to provide feedback or guidance to their children but the goal of completing puzzles likely prompted them to use spatial language to scaffold the activity, much like the app. In contrast, the block and *Minecraft* activities were unstructured. Dyads were invited to build block structures from the structure guide (see Figure 3) but were also told they could build whatever they wanted, as many did. For the 3D activities, mothers may have felt less of a need to guide their children's play, and children may have directed the activities instead, leading them to use more spatial language. However, mothers did ask more questions during 3D activities, the majority of which were information-seeking, perhaps to understand their children's self-directed play. Since the dimensionality of the activities was not included in the research questions of Study 1 and was instead an exploratory analysis, these explanations are offered only as post hoc speculations.

Differences between the puzzle and block activities (and their digital versions) could be likened to the differences between guided play and free play. As described in the Introduction, guided play involves an adult who scaffolds the activity towards appropriate learning goals for the child (Weisberg et al., 2016; Weisberg, Hirsh-Pasek, et al., 2013; Yu, Shafto, et al., 2018). Arguably, a well-designed app like *Dragon Shapes* that scaffolds children's actions and provides feedback could be considered a form of guided play. Although parents were not explicitly instructed to scaffold the physical puzzle activity, the implicit goal of completing the puzzles likely provided its own structure that was reinforced by mothers. But for block play and *Minecraft*, dyads had the choice between using the provided structure guides and playing freely with the materials and, anecdotally, many children preferred to build freely. Further examination of these data could compare mother-child behavior for those who engaged in free play versus those who attempted to build from the guide.

Gender Effects

Despite past research showing sex differences in children's production of spatial words (Pruden & Levine, 2017), Study 1 found no gender effects in children's spatial language. Boys and girls used similar amounts of spatial language across both play contexts. Mothers also did not differ in their spatial talk based on whether they were interacting with boys or girls. However, mothers' question-asking did differ by child gender: for physical play, mothers asked more questions of boys than girls. This effect was driven by the specific and permission subcategories of information-seeking questions.

We can consider this in the context of research showing parents talk differently to boys and girls about topics like science. For instance, parents are three times more likely to explain science at a museum exhibit to boys than girls, even though their overall talk does not differ by child gender (Crowley et al., 2001). Rhodes et al. (2019) found that girls who heard science described in terms of action (e.g., "Doing science means exploring the world!") rather than identity (e.g., "Scientists explore the world!") persisted longer in science games, arguably because identity-focused language raised doubts in girls of their group membership. Considering implicit gender stereotypes predict sex differences in science and mathematics achievement (Nosek et al., 2009; Nosek & Smyth, 2011), even small differences in the language boys and girls are exposed to can have large downstream effects. Though the present studies did not show broad gender effects, dissimilarities in mothers' talk with boys and girls are important to consider.

Spatial Play Intervention

In Study 2, a three-week spatial play intervention conducted in kindergarten and first-grade classrooms revealed no effects of physical or digital spatial play compared to non-spatial play on children's mental transformation, spatial scaling, and spatial visualization. When the physical and digital spatial conditions were collapsed and compared to the non-spatial control condition, there was still no effect of spatial play on children's spatial reasoning skills. Neither prior experience with the spatial materials used in the study, nor frequency of spatial play in general, related to children's outcomes. Although there are several possibilities to explain these null effects, the most plausible is that exposure to spatial play was too limited to be effective. When children engage with physical or digital playful learning activities in school contexts, they typically have daily exposure throughout the school year with the materials. Further efforts to establish a spatial play intervention should take into account the overall length and frequency of play, in addition to the types of materials and measures included. This study employed a wide range of activities but a narrow range of spatial measures; the opposite may prove more effective.

Another factor that may have affected the success of the intervention was the age range. Although Casey et al. (2008) demonstrated effects of a block building intervention with 5- and 6-year-olds, other intervention attempts have focused on children between the ages of 8 and 12 (De Lisi & Wolford, 2002; Subrahmanyam & Greenfield, 1994; Yang & Chen, 2010). On the other hand, children as young as 4 have benefited from play interventions focused on numerical cognition (Ramani et al., 2014; Ramani & Siegler, 2008; Siegler & Ramani, 2008). The age range in the present studies was chosen to strike a balance between these past examples and the suggested age of use for the materials of the intervention. In particular, digital games like *Minecraft* and *Unblock My Car* were expected to be too difficult for children younger than 5 years old, whereas board games like *Chutes and Ladders* and *Candy Land* might have been too childish for those older than 7.

It is worthwhile to note that this study presumed that the causal relationship between spatial play and spatial reasoning would occur in one direction, *from* spatial play *to* spatial reasoning. It is also possible that children with advanced spatial reasoning skills are better at (or more interested in) spatial play, or that a complex relationship exists, wherein children who are advanced in spatial reasoning engage in more spatial play, which in turn leads to higher spatial reasoning and more spatial play, and so on. This study did not preclude such a possibility, but rather assumed the simplest causal path given the existing evidence (e.g., Jirout & Newcombe, 2015; Levine et al., 2012).

Adult Support of Children's Spatial Development

Much of the present research focused on adult behaviors that are believed to contribute to children's learning. How can adults be encouraged to engage with children in ways that promote their spatial development? One method might be to explicitly prompt adults to use spatial language (Borriello & Liben, 2017; Polinsky et al., 2017). Mothers taught about ways to promote spatial thinking subsequently used more spatial language during block play (Borriello & Liben, 2017). Parents instructed to emphasize specific types of spatial content, like shape terms, used more spatial language afterward, which in turn predicted children's spatial language (Polinsky et al., 2017). But adults can also be encouraged to engage with children in ways that indirectly support their spatial reasoning. In a study run at a museum gear exhibit, parents were told to either explain, explore, or engage as usual with their children (Willard et al., 2019). Those told to explain discussed the mechanisms of the gear exhibit more with their children and asked more questions about the gear mechanisms, which then increased children's exploration of the exhibit. Although spatial language was not the study's focus, gear toys require spatial thinking and likely prompted a great deal of spatial language. As I will discuss further in the next section, my future research will include prompting adults to engage children in specific ways during spatial play.

Adults' questions support children's exploration and learning (Yu, Landrum, et al., 2018), but children's questions can also lead to explanations from adults that support learning (Callanan & Oakes, 1992; Kurkul & Corriveau, 2018). Parents respond to "how" and "why" questions with causal explanations (Callanan & Oakes, 1992), particularly in middle-class families (Kurkul & Corriveau, 2018), and these explanations influence children's understanding of the world (Crowley & Siegler, 1999; Lombrozo, 2006). Study 1 did not examine children's questions because they occurred infrequently during the play periods, but future studies should examine whether children's question-asking, and the quality of adults' subsequent explanations, relate to children's learning of spatial content.

Future Directions

The present studies examined features of adult-child interaction and the effects of spatial play separately; future work should investigate them in tandem. As previously discussed, Study 2 included adult facilitators who naturally varied in their guidance, spatial language, question-asking, and other behaviors that may affect children's engagement with and learning from spatial games. My future research will involve coding facilitators' behavior and relating it to children's play behavior and spatial outcomes. Of particular interest is how facilitators support children's digital spatial play and whether it resembles their support of physical play. I also plan to probe the consequences of specific components of guidance (e.g., question-asking, explanations, directing children's actions) and peer-peer interactions (e.g., coordinating actions, turn-taking) on children's spatial outcomes.

Another future direction is to experimentally manipulate the level of guidance that facilitators provide, with high-structure and low-structure contexts within the physical and digital play. It may be that either or both types of play would benefit from facilitators providing high levels of structure. Conversely, digital spatial play may require less structure from a social partner, particularly when the app provides guidance as *Dragon Shapes* did. Although Study 1 found less spatial language and question-asking from mothers during digital play, future studies should explore whether this actually reduces children’s spatial learning from apps, whether prompting spatial language increases its occurrence, and whether app language serves a similar function as parent language.

Lastly, not enough is known about what happens when peers engage together on digital devices. In Study 2, children used iPads in pairs to play digital versions of games like *Connect 4* and *Chutes and Ladders*. How did they cooperate and communicate to successfully complete these games? Did their focus shift flexibly between the device and their partner or did one unequally consume their attention? Are peer-peer interactions during digital board games similar to those during physical board games? These and similar questions will provide promising avenues for future work and have important implications for educational settings, where children are increasingly using digital devices without adult scaffolding.

Conclusion

The value of children’s play goes well beyond entertainment; it can promote learning in a variety of domains, including spatial reasoning (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014). In an increasingly digital world, it’s important to understand how spatial play, whether it occurs in the classroom or through an iPad, impacts children’s spatial development. This dissertation serves as an initial investigation into how children engage with and learn from physical versus digital spatial games, and the results have important implications for educational contexts. Social interaction is argued to be a crucial but underutilized contributor to children’s learning from digital media (Hirsh-Pasek et al., 2015). In demonstrating how mothers change their behavior between physical and digital play, this dissertation adds to the growing collection of research suggesting parents should play an active role in their children’s media exposure. Although the present research does not offer causal evidence for a relation between spatial play and spatial reasoning, it provides a foundation for a comprehensive spatial play intervention program that can contribute to the use of evidence-based practices in early education settings.

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Appendix A

Dragon Shapes Story Transcript

Episode 1 – Butterfly Shapes
Many years ago, in the village of Tan, there lived a well-loved dragon named Druzzle. Late at night, when the people were at home, Druzzle was all alone. He would sit and watch the smoke curl out of the chimneys, making shapes in the night sky. One night, the smoke from the chimney formed into a dragon. As the dragon floated away, Druzzle decided to follow. Druzzle had never left Tan before. Before long, Druzzle was lost. The next morning, the people of Tan were shocked to see that Druzzle was missing. All that remained were some dragon scales. They were all different shapes and sizes. Could the dragon shapes create a clue to find Druzzle? The dragon shapes formed a mysterious butterfly!

Episode 2 – Shape Splash
The butterfly beckoned the people to follow him. A young brave warrior ran after him. He followed the butterfly until they reached a rushing river. The river was much too wide for the warrior to swim across. He reached for the dragon shapes. What could help him cross the river? The dragon shapes formed a giant turtle!

Episode 3 – Mountain Moves
The warrior quickly climbed onto the turtle shell. Together, they chased the butterfly across the river. The warrior followed the butterfly from the dense forest. He followed him over logs and around trees but he still did not see Druzzle. As he emerged from the forest, he saw a steep rocky mountain. This was not looking good for the shape warrior. What could help him climb to the top? The dragon shapes formed a mountain goat!

Episode 4 – Starlight Shapes
The goat had nimble feet and a strong back. They followed the butterfly higher and higher. At the top of the mountain, the warrior could see the village, the river, and the forest, but there was still no sign of Druzzle. As the sun went down, he noticed shapes glowing all around him. These were more dragon shapes. The dragon shapes formed Druzzle! By using the shape skills he had learned along the way, the warrior had saved Druzzle. Druzzle and the warrior quickly made their way home. A great celebration was held. The warrior taught others about the shape arts and became known as the shape master. His knowledge continues to be handed down to this day. And so ends the legend of the first shape master and the helpful shape creatures of Tan.

Appendix B

Study 1 Parent Questionnaire

Please answer each question to the best of your knowledge. You are free to skip any questions you do not wish to answer. We understand that children's activities change often, so estimations are fine.

Please indicate how often your child plays with or uses:

	Several times a day	Once a day	Several times a week	Once a week	Several times a month	Once a month or less
Blocks	☐	☐	☐	☐	☐	☐
Books	☐	☐	☐	☐	☐	☐
Dolls/Stuffed animals	☐	☐	☐	☐	☐	☐
Balls	☐	☐	☐	☐	☐	☐
Outside play	☐	☐	☐	☐	☐	☐
Drawing materials	☐	☐	☐	☐	☐	☐
Building toys	☐	☐	☐	☐	☐	☐
Puzzles	☐	☐	☐	☐	☐	☐
Television	☐	☐	☐	☐	☐	☐
Computers	☐	☐	☐	☐	☐	☐
Tablets/Smartphones	☐	☐	☐	☐	☐	☐

How important do you perceive each of the following play activities to be **for learning**? Please circle your response from 1 (not important at all) to 10 (extremely important).

	Not important									**Extremely important**
Blocks:	1	2	3	4	5	6	7	8	9	10
Books:	1	2	3	4	5	6	7	8	9	10
Dolls/Stuffed animals:	1	2	3	4	5	6	7	8	9	10
Balls:	1	2	3	4	5	6	7	8	9	10
Outside play:	1	2	3	4	5	6	7	8	9	10

Drawing materials:	1	2	3	4	5	6	7	8	9	10
Building toys:	1	2	3	4	5	6	7	8	9	10
Puzzles:	1	2	3	4	5	6	7	8	9	10
Television:	1	2	3	4	5	6	7	8	9	10
Computers:	1	2	3	4	5	6	7	8	9	10
Tablets/Smartphones:	1	2	3	4	5	6	7	8	9	10

How many of these devices are present in your home and, on average, how much time per week does your child use each?

a. _____ Television _______ minutes per week

b. _____ Computer (Type(s):___________________________) _______ minutes per week

c. _____ Smartphone (Type(s):_________________________) _______ minutes per week

d. _____ Tablet (Type(s):______________________________) _______ minutes per week

What **apps or programs** does your child frequently use on tablets, smartphones, or computers?

Has your child ever played the digital game *Minecraft*? Circle: Yes No

a. If yes, how often does your child play *Minecraft*? _______ minutes per week

b. On what type of device (computer, tablet, smartphone)? __________________

Has your child ever played the digital game *Dragon Shapes*? Circle: Yes No

a. If yes, how often does your child play *Dragon Shapes*? _______ minutes per week

b. On what type of device (computer, tablet, smartphone)? __________________

Has your child ever played with physical *Minecraft* blocks? Circle: Yes No

a. If yes, how often does your child play with physical *Minecraft* blocks?

_______ minutes per week

Has your child ever played with physical tangram puzzles? Circle: Yes No

a. If yes, how often does your child play with physical tangram puzzles?

_______ minutes per week

Appendix C

Study 1 Experimenter Script

Dragon Shapes Introduction

Today you'll play an iPad game called *Dragon Shapes*. In this game, you put together shapes like triangles and squares to make a picture. The game has a story about a dragon who gets lost in the forest and a warrior that has to find him. You can start by listening to the first story. Then to play the game, you put the smaller shapes on top of the grey area to make a picture (*display puzzle 3*). When you finish a puzzle by putting all the pieces in the right place, you can move onto the next puzzle. When you finish all the puzzles with the same background, like this one (*point*), then it's time to hear the next story. OK, are you ready to start the game?

Physical Puzzle Introduction

Today you'll play a puzzle game called *Dragon Shapes*. In this game, you put together shapes like triangles and squares to make a picture. The game has a story about a dragon who gets lost in the forest and a warrior that has to find him. You can start by reading the first story. Then to play the game, you put the smaller shapes on top of the grey area to make a picture. When you finish a puzzle by putting all the pieces in the right place, you can move onto the next puzzle. On the back of each puzzle, it says which shapes you need and how many. When you finish all the puzzles with the same background, like these ones (*display several*), then it's time to read the next story. OK, are you ready to start the game?

Minecraft Introduction

Today you'll play an iPad game called *Minecraft*. In this game, you can use blocks to make whatever you want! At the bottom are the different blocks you can use to build. You can tap the one you want (*Demonstrate). To place a block, tap where you want it to go (Demonstrate).* Would you like to try? *(Let child place).* Great! To remove a block, press and hold on the block you want to remove *(Demonstrate).* Would you like to try? *(Let child remove).* To move around, press the arrow of the direction you want to go. To go forward, you press this one, to go backwards, you press this one, and to go to the side, you press this one or this one (*Demonstrate*). You can also change what you're looking at by holding your finger on the screen and moving it around. Would you like to try? *(Let child try).* Now I have these pictures of different things you can build. For each one, you can see how it looks from the front and from the side. So if you want to, you can build some of these! OK, are you ready to start the game?

Physical Block Introduction

Today you'll play a block game called *Minecraft*. In this game, you can use blocks to make whatever you want! In this box are the different blocks you can use to build. You can take blocks out of the box and put them where you want them to go (*Demonstrate*). Would you like to try? *(Let child place).* Great! To remove a block, pick it up and put it back in the box. Would you like to try? *(Let child remove).* When you build something, you can change how you look at it by moving over here or over here, and you can also look at it from above like this (*Demonstrate different visual perspectives*). Would you like to try? *(Let child try).* Now I have these pictures of different things you can build. For each one, you can see how it looks from the front and from the side. So if you want to, you can build some of these! OK, are you ready to start the game?

Appendix D

Pearson Correlations Between Control and Outcome Measures in Study 1

	1.	2.	3.	4.	5.	6.	7.
1. Spatial ability	-						
2. Executive function	.01	-					
3. Verbal ability	.31*	.13	-				
4. M spatial words	.24	-.20	.07	-			
5. M non-spatial words	.34**	-.26*	.25	.76***	-		
6. C spatial words	.04	-.05	.18	.21	.31*	-	
7. C non-spatial words	.06	-.05	.10	.15	.34**	.85***	-

Note. M = Mother, C = Child. * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$.

Appendix E

Round 2 Spatial Intervention Schedule

Day 1 – Blocks/Gears			**Day 2 – Gears/Puzzles**		
Physical 1	Blocks	Jenga	**Physical 1**	Gears	Rush Hour Jr.
Physical 2	Gears	Rush Hour Jr.	**Physical 2**	Tangrams	Connect 4
Digital 1	Minecraft	Balanced Tower	**Digital 1**	Crazy Gears	Unblock My Car
Digital 2	Crazy Gears	Unblock My Car	**Digital 2**	Dragon Shapes	Four In A Row
Non-spatial 1	Magnets	Hi Ho Cherry-O	**Non-spatial 1**	Fishing	Lion In My Way
Non-spatial 2	Fishing	Lion In My Way	**Non-spatial 2**	Coloring	Scrabble Jr.
Day 3 – Puzzles/Blocks			**Day 4 – Blocks/Gears**		
Physical 1	Tangrams	Connect 4	**Physical 1**	Blocks	Set Jr.
Physical 2	Blocks	Jenga	**Physical 2**	Gears	Thinking Putty Puzzle
Digital 1	Dragon Shapes	Four In A Row	**Digital 1**	Minecraft	Set
Digital 2	Minecraft	Balanced Tower	**Digital 2**	Crazy Gears	Free Flow
Non-spatial 1	Coloring	Scrabble Jr.	**Non-spatial 1**	Magnets	Spot It Jr.
Non-spatial 2	Magnets	Hi Ho Cherry-O	**Non-spatial 2**	Fishing	Silly Putty
Day 5 – Gears/Puzzles			**Day 6 – Puzzles/Blocks**		
Physical 1	Gears	Thinking Putty Puzzle	**Physical 1**	Tangrams	Chutes and Ladders
Physical 2	Tangrams	Chutes and Ladders	**Physical 2**	Blocks	Set Jr.
Digital 1	Crazy Gears	Flow Free	**Digital 1**	Dragon Shapes	Snakes and Ladders
Digital 2	Dragon Shapes	Snakes and Ladders	**Digital 2**	Minecraft	Set
Non-spatial 1	Fishing	Silly Putty	**Non-spatial 1**	Coloring	Candy Land
Non-spatial 2	Coloring	Candy Land	**Non-spatial 2**	Magnets	Spot It Jr.

Appendix F

Study 2 Parent Questionnaire

Please answer each question to the best of your knowledge. You are free to skip any questions you do not wish to answer. We understand that children's activities change often, so estimations are fine.

Please indicate how often your child plays with or uses:

	Several times a day	Once a day	Several times a week	Once a week	Several times a month	Once a month or less
Blocks	☐	☐	☐	☐	☐	☐
Books	☐	☐	☐	☐	☐	☐
Dolls/Stuffed animals	☐	☐	☐	☐	☐	☐
Balls	☐	☐	☐	☐	☐	☐
Outside play	☐	☐	☐	☐	☐	☐
Drawing materials	☐	☐	☐	☐	☐	☐
Building toys	☐	☐	☐	☐	☐	☐
Puzzles	☐	☐	☐	☐	☐	☐
Television	☐	☐	☐	☐	☐	☐
Computers	☐	☐	☐	☐	☐	☐
Tablets/Smartphones	☐	☐	☐	☐	☐	☐

How important do you perceive each of the following play activities to be **for learning**? Please circle your response from 1 (not important at all) to 10 (extremely important).

	Not important							**Extremely important**		
Blocks:	1	2	3	4	5	6	7	8	9	10
Books:	1	2	3	4	5	6	7	8	9	10
Dolls/Stuffed animals:	1	2	3	4	5	6	7	8	9	10
Balls:	1	2	3	4	5	6	7	8	9	10
Outside play:	1	2	3	4	5	6	7	8	9	10

Drawing materials:	1	2	3	4	5	6	7	8	9	10
Building toys:	1	2	3	4	5	6	7	8	9	10
Puzzles:	1	2	3	4	5	6	7	8	9	10
Television:	1	2	3	4	5	6	7	8	9	10
Computers:	1	2	3	4	5	6	7	8	9	10
Tablets/Smartphones:	1	2	3	4	5	6	7	8	9	10

How many of these devices are present in your home and, on average, how much time per week does <u>your child</u> use each?

_____ Television ________ minutes per week

_____ Computer (Type(s):______________________________) ________ minutes per week

_____ Smartphone (Type(s):____________________________) ________ minutes per week

_____ Tablet (Type(s):________________________________) ________ minutes per week

Has your child *ever* played with the following games, toys, apps (or similar):	**Does your child play this on <u>Digital</u> devices?**		**Does your child play this with <u>Physical</u> materials?**	
Minecraft blocks, Minecraft app	Yes No	______Min/wk	Yes No	______Min/wk
Tangram puzzles, Dragon Shapes app	Yes No	______Min/wk	Yes No	______Min/wk
Gear toys, Crazy Gears app	Yes No	______Min/wk	Yes No	______Min/wk
Connect 4, Four in a Row app	Yes No	______Min/wk	Yes No	______Min/wk
Jenga, Balanced Tower app	Yes No	______Min/wk	Yes No	______Min/wk
Rush Hour, Unblock My Car app	Yes No	______Min/wk	Yes No	______Min/wk
Chutes/Snakes & Ladders game or app	Yes No	______Min/wk	Yes No	______Min/wk
Set or Set Jr. game or app	Yes No	______Min/wk	Yes No	______Min/wk
Silly putty, Thinking Putty puzzle or Flow Free app	Yes No	______Min/wk	Yes No	______Min/wk
Coloring, coloring app	Yes No	______Min/wk	Yes No	______Min/wk
Magnets, magnet app	Yes No	______Min/wk	Yes No	______Min/wk

Fishing toys/games, fishing app	Yes No	______Min/wk	Yes No	______Min/wk
Scrabble, Scrabble Jr.	Yes No	______Min/wk	Yes No	______Min/wk
Hi Ho! Cherry-O	Yes No	______Min/wk	Yes No	______Min/wk
Lion in my Way	Yes No	______Min/wk	Yes No	______Min/wk
Candy Land	Yes No	______Min/wk	Yes No	______Min/wk

Appendix G

Pearson Correlations Between Control and Spatial Measures in Study 2

	1.	2.	3.	4.	5.	6.
1. Age	-					
2. Verbal ability	.46***	-				
3. Executive function	.58***	.59***	-			
4. Mental transformation	.36**	.54***	.47***	-		
5. Spatial scaling	.32*	.31*	.52***	.43**	-	
6. Spatial visualization	.32*	.38**	.59***	.53***	.63***	-

Note: * $p \leq .05$, ** $p \leq .01$, *** $p \leq .001$.

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