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The development and support of geometric and spatial concepts in preschool- and kindergarten-aged children

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Abstract

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The Development and Support of Geometric and Spatial Concepts in Preschool- and Kindergarten-Aged Children

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ABSTRACT

The purpose of the literature review is to discuss the development of geometric and spatial concepts in preschool- and kindergarten-aged children. This development can be seen through the children's mental and manual rotation, as well as children's experiences with spatial reasoning. The factors that influence these concepts, such as spatial talk and spatial play are also examined. This review identifies ways that teachers can support the development of geometric and spatial concepts in the classroom, such as exposure to materials, pedagogy, interventions, and their own professional development. The conclusion of this literature review synthesizes the evidence, discusses recommendations, and provides planning for future research.

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Chapter I: Introduction

Geometric and spatial reasoning has often been ignored in the research that is done within early childhood mathematics. Clements (2004) tells us that in the early ages, there is a lack of materials to introduce children to the ideas of spatial concepts. Research suggests that children who have the opportunity to develop these skills earlier in life will have greater mathematics outcomes in high school and go on to pursue advanced degrees (Newcombe, 2010). Children learn about geometric and spatial concepts in their everyday lives and there are also a variety of interventions that can be done in the classroom to support these skills.

In this chapter, I describe what geometric and spatial concepts are in the context of preschool- and kindergarten-aged children. I then explain why this topic is important in the world of early childhood and what research can do to help teachers support geometric and spatial concepts in the classroom. I then list and define key vocabulary terms and acronyms that will appear throughout the paper. Finally, I share and describe the research questions that will guide this paper.

Geometric and Spatial Concepts in Preschool and Kindergarten

When people are asked to think about different geometric and spatial concepts and how they relate to their lives, many draw a blank. This is a topic that is often not discussed, even among many professional early childhood educators. When defining these concepts at the preschool and kindergarten level, one must think about how children look at the world. Newcombe (2010) states that spatial thinking is all about objects, their shapes, and the relationships that they have with each other. It is also about how these shapes are moved and the paths that they take as they are manipulated. When connecting these ideas to a preschool and kindergarten level, we are looking at how children interact with shapes, puzzles, blocks, maps and mazes, how they manually and mentally rotate objects, how they gesture, and the words that they use when they are describing the space around them.

Research in the education field often passes by the idea of geometric and spatial concepts in the early years. For years, many thought that these skills were fixed and would be pointless to explore, as there was nothing that could be changed. Hawes, LeFevre, Xu, and Bruce (2015) tell us that research on this is often ignored as it is a concept of mathematics that people thought was not malleable; people believed you either had it or you didn't. Measurement of spatial skills, and specifically mental rotation, is not assessed on children under five, as most assessments are meant for older children and adults (Frick, Hansen, & Newcombe, 2013). In order to assess these younger students, researchers have had to adjust their data collection process and the tasks that are done to make them less cognitively demanding.

Although research is just starting to take place to learn about geometric and spatial skills in the preschool and kindergarten classroom, the data is telling us a lot. Research suggests that these skills are malleable. A link has been found between spatial and mathematical skills such that, when they are taught in the early years, a "two-for-one" effect results in increases in both spatial and mathematical skills when different activities and interventions are integrated into the classroom (Cohrssen, Church, Ishimine, & Tayler, 2013; Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014).

The Importance of Geometric and Spatial Concepts in the Preschool and Kindergarten Classroom

Geometric and spatial concepts in the preschool and kindergarten classrooms are important for several reasons. In this section, I discuss these skills in conjunction with how they can predict STEM careers, what research has been done, and how these skills are malleable.

STEM careers and geometric and spatial skills. Geometric and spatial skills are seen in simple everyday activities, such as putting together a baby crib or determining what size of box you will need to pack away your summer clothes. These skills are also seen in high demand careers, such as engineers or air traffic controllers (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014). In these careers, mistakes or low spatial skills can sometimes be life threatening. When we look at the future of geometric and spatial skills, we see that many spatial abilities can help to prepare students for different STEM disciplines. Verdine, Golinkoff, Hirsh-Pasek, and Newcombe (2014) tell us that studies on spatial competence in grade school have shown students to be put on a path towards STEM fields in high school and into adulthood. This suggests that if we can help students to develop spatial concepts from early childhood on, we will potentially increase the number of adults in STEM careers. Those who have a solid foundation of these concepts are usually more interested in science and mathematics, have high quality spatial skills, and are more likely to get advanced degrees (Newcombe, 2010). Those who are taking courses and pursuing degrees in STEM careers have the ability to mentally transform shapes, which can be a predictor of the career path that they will choose (Harms, 2012).

Organizations and agencies in the adult world are becoming aware of how important it is to develop spatial skills starting at an early age in order to be successful in a variety of

STEM careers. By researching how these skills develop in preschool- and kindergarten-aged children, we will better know how to develop them in the early childhood classroom.

Research on geometric and spatial skills. Studies on geometric and spatial skills with preschool- and kindergarten-aged children have been scarce. Despite these lack of studies, what is being done has shown promise for early childhood. Evidence exists that spatial and mathematical skills and abilities can emerge earlier than previously thought (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014). Research suggests that geometric and spatial skills that are learned at the preschool and kindergarten level help to prepare students for mathematical and abstract reasoning in their future schooling (Sparks, 2013).

The research that has been done on this topic suggests that the past view of these skills as being unmalleable is wrong. Research is beginning to indicate that geometric and spatial skills are malleable and should be developed at a young age.

Geometric and spatial skills are malleable. Many careers and life experiences require geometric and spatial knowledge. Children who do not develop these skills will struggle as adults (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014). If we take the time to provide specific geometric and spatial experiences, even our youngest children will be ready for the 21st century with skills to match.

Newcombe, a professor at Temple University, has conducted extensive research on spatial skills since 1981. An article in *American Educator* (Newcombe, 2010) provides us with important information on spatial skills. She observed that Americans often believe that their general academic abilities are fixed, but that growing evidence suggests this is not true; more skills can develop with experience. Children's spatial ability, especially how they perceive spatial structures, has been acknowledged for its influence on how young children develop mathematical skills (Bobis, 2008). Newcombe (2010) states that experience and exposure are what help to build geometric and spatial skills, and that elementary school children's spatial thinking improves more over the school year than it does over the summer months. This suggests that when children are given a chance to learn the information, their skills adapt and grow.

Research suggests that children begin their lives with different abilities of geometric and spatial skills. Regardless of where they begin, they will improve if given the opportunity. Newcombe (2010) states that children with low ability spatial skills need to master an initial hump before they can start to improve their abilities. The more they persist, the faster they will improve. High ability students do not face the initial hump, but just as the low ability children, the more they persist, the faster they will improve.

Supporting Geometric and Spatial Concepts in Preschool and Kindergarten

Supporting geometric and spatial concepts in the preschool and kindergarten classroom is beneficial to both teachers and students. In this section, I discuss the need to educate teachers and other early childhood professionals. I move on to discuss how interventions can help to close the gender and socioeconomic gap that starts to appear in early childhood.

Educate teachers and early childhood professionals. The purpose of this review is to educate teachers and early childhood professionals about geometric and spatial concepts in the preschool and kindergarten classroom. Ginsburg, Lee, and Boyd (2008) report that, typically, early childhood educators are poorly trained to teach mathematics, rarely teach it (and if they do teach it, then it is badly taught), do not believe that mathematics is important to teach, or are afraid to teach it. Teachers need to feel confident in their personal understanding of these mathematics concepts so that they are able to start teaching them in their classroom and are able to notice when they can integrate them throughout the day (Newcombe, 2010). To give teachers the confidence to teach geometric and spatial concepts in the classroom, Verdine, Golinkoff, Hirsh-Pasek, and Newcombe (2014) tell us that there is a great need to train them about the best methods for teaching these concepts. They state that many teachers feel anxiety about teaching these topics and that research shows the more anxiety teachers feels about teaching spatial concepts, the lower their students' spatial skills typically are. Newcombe (2010) tells us that teachers of every grade need to avoid instilling thoughts of anxiety about spatial tasks in students, as this can impede their performance.

Educators have to have an understanding of mathematics as a whole in order to teach it properly. To teach geometric and spatial concepts properly and to give their students a quality education, teachers need to know the trajectories of these concepts (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014). Teachers who know where to begin teaching geometric and spatial concepts in their classrooms will understand how to better incorporate these concepts into their lessons.

Cohrssen et al. (2013) tell us that early childhood educators typically receive more training in teaching literacy than in mathematics. La Paro et al. (2009) found that mathematics teaching was observed 6% of the preschool day, whereas language and literacy was observed for 14% of the day. The National Association for the Education of Young Children and the National Council of Teachers of Mathematics (NCTM) Early Childhood Mathematics Position Statement (2010) proposes that if we want to improve America's proficiency in mathematics, then we need to give it even more attention in the classroom. The position statement asserts that efforts have been made to increase awareness of early literacy; we need to do the same for mathematics. Even where I work, literacy has been the main focus and mathematics has been overlooked quite a bit. Understanding the different interventions and professional development opportunities that exist will help teachers to gain more knowledge about this topic. This, in turn, will allow them to start implementing it in their classrooms.

Early childhood teachers and professionals also need to understand that research is encouraging them to begin teaching geometric and spatial concepts in the early years. Clements (2004) tells us that National Council of Teachers of Mathematics (NCTM) standards are trying to shift teachers away from basic number sense in mathematics, yet most teachers still focus their curriculum on mastery of numerical skills. Verdine, Golinkoff, Hirsh-Pasek, and Newcombe (2014) report children who are exposed to these concepts and develop them throughout their childhood will have more prior knowledge to connect to new concepts later in life. Spatial concepts are key in preparing students for STEM careers (Verdine, Golinkoff, Hirsh-Pasek, & Newcombe, 2014) and educators need to be comfortable teaching these concepts in their classrooms.

The National Association for the Education of Young Children (NAEYC) states that teachers need to be intentional about what they are teaching (Copple & Bredekamp, 2009). Intentional teaching means to be thoughtful and purposeful in every part of the day. They need to intentionally plan and intentionally act on those plans (Jung & Conderman, 2013). NAEYC has made efforts to continue to improve mathematics knowledge in the early childhood community, but there is still resistance as some feel that intentionally planning in the preschool classroom is developmentally inappropriate (Ginsburg et al., 2008). Despite these thoughts, geometric and spatial skills involve concepts that need to be intentionally taught in the classroom in order for children to be introduced to the depth of knowledge that accompanies them.

Early interventions can help to close the gap of gender and socioeconomic status. Early interventions can help to build geometric and spatial concepts and to close the gender and socioeconomic status gap that is often seen with these concepts. In some studies, the gender gap is seen starting as early as age five (Ehrlich, Levine, & Goldin-Meadow, 2006), and the socioeconomic gap is seen as early as age three (Verdine, Golinkoff, Hirsh-Pasek, Newcombe, Filipowicz, & Chang, 2014). Early interventions can be used by teachers and other professionals to close the gender and socioeconomic status gap that can be seen emerging when geometric and spatial skills are observed closely.

The purpose of this review is to learn how children acquire these skills and what interventions can be done to most effectively teach them. Using spatial words can improve language and mathematics performance, as it helps to encode important spatial information for children to recall at a later date (Verdine, Golinkoff, Hirsh-Pasek, Newcombe, Filipowicz, et al., 2014). Using mathematical talk and spatial language will help to support children's emerging understanding of these concepts (Cohrssen et al., 2013). Along with language, using and teaching children to use gestures can be helpful. This can assist the teacher or adult in understanding the child more thoroughly (Verdine, Golinkoff, Hirsh-Pasek, Newcombe, Filipowicz, et al., 2014), and can also help the child to add to their spatial lexicon. These interventions and many more will be examined in this literature review to determine what is most effective in supporting the development of geometric and spatial concepts in preschool- and kindergarten-aged children.

Vocabulary Terms and Acronyms

For the purpose and better understanding of the acronyms and terms used in this review, I define the following:

Canonical vs. Non-canonical: A canonical shape is the traditional version of the shape, such as an equilateral triangle. A Non-canonical shape is the nonstandard version of a shape, with varied angles and sides, such as an isosceles triangle. (Resnick, Verdine, Golinhoff, & Hirsh-Pasek, 2016).

CMTT: Children's Mental Transformation Task; 2D mental transformation task which includes horizontal translation, diagonal translation, horizontal rotation, and diagonal rotation. Used for children 4-7 years old (Levine, Huttenlocher, Taylor, & Langrock, 1999).

Didactic Instruction: The experimenter or adult is the active participant and explores a concept while children watch (Fisher, Hirsh-Pasek, Newcombe, & Golinkoff, 2013).

Free Play: Children are given the opportunity to play with specific materials but can do with them what they want. (Fisher et al., 2013).

Geometric Concepts: Knowledge about shapes.

Guided Play: Children are taught skills and concepts in a playful and exploratory manner. They are guided by careful and intentional planning by the teacher, who is seen as a collaborative partner in learning (Fisher et al., 2013).

Kindergarten: Children who are 5 years old at the start of the school year, turning 6 during the year.

Preschool: Children who are in school any time before kindergarten, usually children aged three to five years old.

Rotated, Rotation: Turning a shape around the center point, which stays fixed. Turning the shape by a certain number of degrees (Rotated 45°, 90°, etc.).

Spatial Concepts, Spatial Ability, spatial thinking: The ability to reason about space (Jirout & Newcombe, 2015). "The ability to generate, retain retrieve, and transform well-structured visual images" (Hawes & LeFevre et al., 2015, p. 10).

Spatial Talk, Words: Words referring to the dimension of an object (big, fat, tall, little), the shape (circle, rectangle, octagon), and spatial properties (bent, curvy, flat, edge) (Pruden, Levine, & Huttenlocher, 2011).

Translation: The movement of a 2D shape to a different spot. Shape cannot be rotated or resized, simply moved.

Research Questions

This literature review examines the relationships of geometric and spatial concepts in the context of how preschool- and kindergarten-aged children learn them most effectively and how teachers can support the development of these concepts in the classroom. In order to build these concepts in our children, teachers need to know what interventions are effective in the classroom. This review will answer the following questions:

1) How do preschool- and kindergarten-aged children develop geometric and spatial concepts?
2) How can teachers support the development of geometric and spatial concepts in the preschool and kindergarten classroom?

Chapter II: Literature Review

This review investigating geometric and spatial concepts in the preschool and kindergarten classroom looks at how these concepts develop and what influences them in early childhood. It also looks at effective interventions that can be done with preschool- and kindergarten-aged children. It will help teachers to understand what they can do to help prepare themselves for introducing these topics in the classroom. The questions that will be answered within this review are:

1) How do preschool- and kindergarten-aged children develop geometric and spatial concepts?
2) How do teachers support the development of geometric and spatial concepts in the preschool and kindergarten classroom?

Many geometric and spatial concepts are discussed in this review. Children develop the basics of these concepts through spatial talk, play, mental and manual rotation, and through solving a variety of problems that involve spatial reasoning. Teachers can support the development of this concept through exposure to materials, pedagogy, interventions, and professional development.

The Development of Geometric and Spatial Concepts in Preschool- and Kindergarten-Aged Children

The development of geometric and spatial concepts in preschool- and kindergarten-aged children can be seen in a variety of ways. Basic research on these concepts informs teachers of the development that is often seen in early childhood, while applied research examines the factors that influence the development of geometric and spatial concepts. The research discussed in this section informs us of the development of geometric and spatial concepts through mental and manual rotation, spatial reasoning, spatial talk, and spatial play.

How Do Geometric and Spatial Concepts Develop?

Mental and manual rotation are spatial concepts that develop in the early years. Hawes and LeFevre et al. (2015) developed an age appropriate 3D mental rotation task and used this task to learn about 3D mental rotation in the early years. They also used the study to compare the relationship between 2D and 3D mental rotation. The authors chose 165 children between the ages of four and eight to study. They were from four urban schools in Canada and were from a lower socioeconomic class. The researchers administered a 2D mental rotation task from the Children's Mental Transformation Task (CMTT) and also an executive functioning task. The 2D mental rotation task showed children a bisected example shape and then gave choices of which of three shapes would put the example shape back together. Two to three days later, they administered the 3D mental rotation block task. This task had 16 items, each of which were shown to the children. Each item had 4 block figures: one main, one mirrored, one rotated, and one with different positioning. The children were asked to find the same block (the rotated version) and to rotate it so that it looked like the example. They received feedback from being able to rotate it and from the researcher and were allowed to try another option if they chose the wrong block. The data gathered indicated that children in the 4-to 5-year-old group did not perform above chance on the 2D task. On the 3D task, they performed a little better but not significantly different from chance. Children who were successful rotators did significantly better on the 2D task than those who were not. This research indicated that as age increased, there was less guessing and more choosing of the correct answer; at age seven choosing the correct answer happened more consistently. The progression that was determined for this set of rotation skills moves from guessing to mirror confused (those who could not tell the difference between the example and its mirror image) to successful rotators. Knowing this progression allows teachers to know students' abilities and the experiences that still need to be provided in the classroom.

Frick et al. (2013) also studied mental rotation in young children. They conducted two experiments to test 2D and 3D mental rotation in children between the ages of three and five. The first experiment consisted of 60 children; 20 each of 3-, 4-, and 5-year-olds. These children were predominantly Caucasian, middle-class, English speaking, and lived in a suburban United States area. In the first experiment, the researchers used 3D shapes and asked children to find the piece that was similar to put into a hole, as in a puzzle piece. They asked children to do this with shapes that were rotated at 0°, 45°, 135°, and 180°. Direct feedback was given when the shape that was chosen did not fit into the hole. The results of this experiment showed that the boys struggled and showed lower accuracy than the girls for the 135° angle. The girls, in turn, struggled and showed lower accuracy with the 180° angle. Two of the 3-year-olds, 8 of the 4-year-olds, and 19 of the 5-year-olds showed above chance performance. By age five, all but one were above chance. The participants from the second experiment came from the same population, but consisted of 40 children; 20 each of 4-and 5-year-olds. In experiment 2, the researchers used 2D paper cutouts instead of 3D shapes. Children were told to point to the cutout that they believed would fit into the "hole" in the paper. They were told to only point and not pick up the paper, therefore no feedback was given to them. Seven of the 4-year-olds and 13 of the 5-year-olds performed above chance. In the 2D experiment, accuracy decreased when a larger angle rotation was presented to the children. Visuals and feedback did not have a significant effect on the rotation performance of the 4-and 5-year-olds. Overall, great improvement in mental rotation ability was seen from the age of three to five years old.

The development of spatial reasoning skills and their relationship with quantitative reasoning was studied by Tian and Huang (2009). This study was done in the Southwest of China and participants were from 4-and 5-year-old preschool classrooms to grade 1. A total of 1,887 children from 10 different elementary schools were studied. Of this number, 311 were kindergarten age (that is, under age six); 198 were urban and 113 were rural. The overall study was conducted with children who were 48 months to 95 months old. Tian and Huang (2009) wanted to gain insight on the development and relationships between spatial and quantitative reasoning abilities. To do this, they adapted a counting and spatial picture from a text book, where some parts of houses, doors, and flower beds were hidden. Children were asked a set of three questions:

1) How many rows of houses are in the picture?
2) How many doors are in the houses altogether in the picture?
3) How many flower beds are in front of the houses altogether in the picture?

Question 1 tested children's spatial reasoning abilities (either high-spatial level, middle [or fuzzy] level, or low [plane] level). Questions 2 and 3 tested children's quantitative reasoning ability (either high-abstract computation level, middle conjecture computation level, or low-literal computation level). A subset of the participants were then asked questions about their thought process of how and why they answered the questions the way that they did. Almost 75% of the participants answered question 1 correctly, suggesting that most children in this age range have a relatively high spatial reasoning ability. The percentage of children who answered question 2 and 3 correctly were 31.94% and 40.76%

respectively. This study concluded that, since few children could not identify the spatial patterns in the picture, children's understanding of spatial concepts could develop earlier than their understanding of geometric figures. Spatial reasoning ability also develops earlier than quantitative reasoning ability; about 18 months earlier. The research found that spatial reasoning abilities improved dramatically from 5.6- to 5.11-years-old. The authors termed this as the "rapid improvement" stage. In this stage, females' spatial abilities improved significantly more than the males.

Spatial reasoning skills were also researched by Verdine, Golinkoff, Hirsh-Pasek, Newcombe, Filipowicz, et al. (2014). This team of researchers questioned how spatial assembly performance related to early mathematics skills, even as young as age three. The researchers gathered 102 preschoolers between the ages of 38 and 48 months. These children were from Head Start, private schools, and university schools and were all native English speakers. The students were asked to complete the 3D Test of Spatial Ability (3D TOSA) where they were asked to replicate block structures made out of interlocking Mega Blocks, starting from easier structures and working to more complex. While scoring the students' attempts, the researchers looked at translation, rotation, and vertical location of the structures that were built. The students were then given the Early Mathematics Assessment System (EMAS) to test early mathematical skills. The results show that the structures that were more complex and had more pieces were harder for the students to copy. It was also difficult for students to correctly align the MegaBlocks according to the number of pips that connected them together (For example, the 2 pip x 2 pip sat on top of the 2 pip x 4 pip block in the center, rather than to a side). Of the 3 skills targeted, translation was the most difficult, especially as the designs of the structures became more complex and the counting of pips was more relevant. Rotation was also a difficult skill for this age but not as difficult as translation. Vertical location was the easiest, but does not seem to be as related to mathematical skills as translation is. This study shows that the more complex the characteristics of an object are, the more trouble children of this age have thinking of it in different ways. From the data gathered in this study, the researchers hypothesize that permitting children to play with blocks and to gain more experiences will allow them to decompose blocks into different components, thus possibly increasing spatial and mathematical skills.

A task as simple as paper folding can help to determine the development of spatial transformation and reasoning in young children. Harris, Newcombe, and Hirsh-Pasek (2013) conducted two studies that looked at the development of dynamic spatial transformation (one's ability to form and mentally manipulate how objects are represented spatially). Study 1 consisted of 180 children between the ages of four and seven, with 60 to 65 month olds being recruited more heavily. These participants were predominantly Caucasian and middle-class. In study 1, children were presented with the Mental Folding Task for Children (MFTC) which presented them with a binder that had a prompt on one side and four answer options on the other. The prompt showed the children where the paper would be folded and answer options were given. One of the answer options was the correctly folded paper and three were incorrect forms. The children were also given the CMTT to assess mental transformation. In study 2, 27 of the same children returned for a second test six months later. This study was a follow up of the same tests done to investigate the growth with respect to the children's initial ability in spatial transformation. The majority of the children were not successful at the MFTC until about five to six years of age, which tells us that the spatial skills needed to mentally fold and transform shapes appears around the 5th or 6th year of life. A higher performance on the CMTT did not predict later folding ability, but a lower performance did predict that the future scores on the MFTC would be in the lower range. The authors tell us this educates teachers in knowing that they must draw students' attention to spatial relations in the classroom. Teachers must intentionally use spatial terms and provide time for spatial activities, thus allowing the development of spatial reasoning to occur.

What Factors Influence the Development of Geometric and Spatial Concepts?

The amount of spatial talk that children hear from when they are young has a great impact on their own spatial language and development (Pruden, et al., 2011). Pruden et al. (2011) studied 52 children, aged 14 to 46 months and again at 54 months, and their caregivers. These racially diverse participants were from the Greater Chicago area, were English speaking, and were from families with an average income of $50,000-$70,000 annually. Pruden et al. (2011) studied the relationship between children and parents' spatial talk when controlling for "other talk." The researchers visited the homes of each parent-child dyad for a total of 9 times to video-record and observe the amount of spatial talk that was used over a 90 minute period. This was done from when the children were aged 14 to 46 months. At age 54 months, the researchers collected scores on the children's performance on the Spatial Transformation Task, the Block Design Subtest from the Wechsler Preschool and Primary Scale of Intelligence (WPPSI-III), the Spatial Analogies Test, and the Peabody Picture Vocabulary Test. The data from the observations and the tests revealed that parents who produced more spatial language had children who produced more spatial language. The more spatial language a child produced, the better they scored on the spatial tasks. These results raise the possibility that spatial language used when children are younger may help to predict their later spatial and mathematical performance.

Spatial talk in block building was also studied to see if it had an influence on spatial concepts. Ramani, Zippert, Schweitzer, and Pan (2014) studied 76 racially diverse preschool children from middle-class families. Same sex dyads of these participants were given a goal of building a house with 4 walls, a way to get inside and at least 2 rooms in 8 minutes. Given verbal prompts, the dyads were then asked to explain their structures. The researchers were interested in the amount of task-related talk within the dyads. Children's talk was associated with the features of the houses that the children built. Boy dyads engaged in more task-related spatial talk compared to girls and built structures that had more house features. The researchers conclude that spatial talk affects not only the features that the pairs included in their block structures, but it also helped to increase the team work that was seen between each partner pair. As the dyads discussed the design of their houses, they were focused on mathematical-related concepts, integrating spatial vocabulary and number sense into their play conversations. Working towards a common goal in this somewhat guided activity helped to bring out specific spatial and mathematical vocabulary from children.

Spatial play also has an important influence on the development of geometric and spatial concepts. Jirout and Newcombe (2015) looked at 847 racially diverse 4-to 7-year-olds. The participants were equally split between sexes and were from a variety of socioeconomic backgrounds. The researchers took data from the WPPSI-IV database, Block Design Subtest, and home environment questionnaires to investigate specific aspects of spatial play. Along with these two sources of information, they also looked at general intelligences using the Full-Scale IQ (FISQ) section of the WPPSI-IV. The authors looked at spatial play and its influence on spatial thinking while controlling for general intelligence and other behaviors. The results of their study show that males outperformed females in spatial concepts; however males also participated more frequently in spatial play. The researchers also found that the frequency in which children played with spatial toys (such as puzzles, blocks, and board games) had a significant main effect on the Block Design scores from the WPPSI-IV. The authors found that spatial play is positively associated with spatial skills, suggesting that spatial play may have an effect on the development of spatial skills. The relationship between non-spatial play and the Block Design scores was null. The authors also found that there was no relationship between non-spatial play and the Block Design scores.

Puzzle play was studied to see if it would be a predictor of preschoolers' spatial transformation skills. Levine, Ratliff, Huttenlocher, and Cannon (2012) studied 53 parent-child dyads from the Chicago metropolitan and surrounding areas. The dyads all spoke English and had a variety of socioeconomic and educational backgrounds. The authors questioned whether those children who engaged in puzzle play during the ages of 26 to 46 months would have a higher score on spatial transformation tasks at the age of 54 months. The researchers also collected data to see if the frequency of the children's puzzle play and the quality of their play predicted their spatial transformation skills. To collect their data, the researchers made visits to the participants' homes from when they were 14 months to 46 months old. The researchers video-recorded 90 minutes of the parent-child interactions that were observed. These observations were coded for puzzle play, frequency, quality, and spatial language. At 54 months, the children were given a 10-item version of a spatial transformation task. The authors discovered that children who played with puzzles had a higher score on the spatial transformation task than those who did not play with puzzles. The frequency of puzzle play was significantly related to the children's spatial transformation scores. Higher scores were associated with more frequent puzzle play. Next, the authors looked at the quality of play and its association with the spatial transformation task. They found that there was a significant interaction effect of puzzle play quality and gender on the spatial transformation task; girls with higher puzzle play quality scored higher on the spatial transformation task. However there was no interaction between puzzle play frequency and puzzle play quality. This leads the researchers to the understanding that frequent puzzle play, and quality puzzle play for girls, is what leads to higher scores on the spatial transformation task.

Ping, Ratliff, Hickey, and Levine (2011) conducted a study to determine which had more of an influence on mental rotation: being able to manually manipulate a joystick to see a 2D object move on a screen, or gesturing the movement but not actually seeing the object move. Sixty-three 4-year-olds from Chicago and its nearby suburbs participated in this research study. These children were first given the CMTT and the Mental Rotation Task (MROT) as a pretest. They were then randomly assigned to three training groups: rotation training condition, gesture training condition, or an unrelated game. In the rotation training condition, the children were asked to rotate the objects (animals) on the screen with a joystick so the objects were both looking the same way. They were able to see the animals move when they moved the joystick. In the gesture training condition, the children were told to touch their hands to the screen and to gesture how they would move the animal to stand it on its feet. The children did not actually see the animals move, they simply gestured about it. In the unrelated game, the children were given a literacy activity. The children were then given the CMTT and MROT again as a posttest. The research from this study indicates that those who were in the rotation and gesture training group improved more than those who were simply in the control group. Students in the gesture training group improved the most from pre- to post-test. These findings were significant and the researchers suggest that children seeing the objects visually rotate in front of them may become dependent on the visual cue and might not show the same level of mental rotation skills or improvement. They suggest that training children to gesture about rotation will help to develop and improve their mental rotation skills.

Teachers' Support of the Development of Geometric and Spatial Concepts in Preschool- and Kindergarten-Aged Children

Teachers can support the development of geometric and spatial concepts by taking simple actions in preschool and kindergarten classrooms. In this section, I discuss the effects of exposure to materials, pedagogy, interventions, and professional development for teachers.

Exposure to Materials

Geometric shapes are often seen in many early childhood classrooms. Resnick et al. (2016) studied what specific shapes were presented in the classroom, how they were presented to children, and if any information about the shapes was critical to the development of shape skills in children. The researchers collected 29 shape books, 20 physical sorters, and 20 shape focused apps. In these materials, the shapes were found and identified, coded as canonical (the most common form of seeing a shape; for example, equilateral triangle) or non-canonical (the less common form of seeing a shape; for example, isosceles triangle), and then described as either being in an isolated geometric form, an embedded geometric form, an isolated object, or an embedded object. It was found that the most common shape across all materials was a circle; the least common was a rectangle. This lends itself to being consistent with past research from Clements, Swaminathan, Hannibal, and Sarama (1999) and Verdine, Lucca, Golinkoff, Newcombe, and Hirsh-Pasek (2016) (as cited in Resnick et al., 2016) that a circle is the most commonly known shape, compared to a rectangle that is not as accurately identified. The other shapes found were square, triangle, pentagon, hexagon, octagon, and star. Applications and books had a greater variety of shapes than sorters and books tended to include more non-canonical shapes. Books also tended to represent shapes in a more embedded geometric form (ex: a triangular sandwich) than did apps and sorters, although there was no statistical difference in how books and apps represented the shapes. With shapes being in an embedded geometric form, Resnick et al. (2016) recommend that teachers first look at the object (sandwich) and then point the attention of the child towards the shape of the object. Fifty-one percent of the books that were researched also provided a definition of the shape, whereas apps and sorters did not. Overall, the findings of this study tell us that children are exposed to a very limited variety of shapes, especially those that are not typical. From these findings, the authors suggest that there is a need for learning materials to provide more variety and detail about shapes that are rarely mentioned or seen in the early childhood classroom.

Pedagogy

Pedagogy plays an important role in how children interact and remember certain information. Fisher et al. (2013) conducted a study in a suburban Philadelphia area. The 60 children between the ages of four and five were predominantly Caucasian and upper middle-class. This study was done to see if children's shape knowledge was malleable and if so, was there a specific type of pedagogical approach that was more effective than another in supporting this knowledge. To answer these questions, the researchers conducted an experimental condition, followed by a shape sorting task. In the experimental condition, shape cards were made with typical, atypical, and non-valid shapes (for example, equilateral triangle, acute triangle, three lines that do not all connect). The experimenter looked at these shapes as either "real" (typical and atypical) or "fake" (non-valid) although he did not communicate this directly to the children. The children were divided equally into one of three groups, each having a set of shape cards. In the first group, the experimenter taught the children by guided play, where he explored the shapes with the children and asked them to figure out why they were "real" shapes. He questioned the children and helped them to discover the features of each shape that was shown. In the end, the children were allowed to make their own shapes similar to those on the training cards. In the second group, the researcher taught the children by using a didactic instruction method. This was presented using similar wording to the guided play group, but the children only watched what the researcher did. The children's engagement was the only difference from this group and the guided play group. The third group was taught using a free play method. In this group, the researcher laid out the shape cards and the children were free to explore them for 7 minutes. Following the exploration, they were given 6 minutes to build shapes with shape sticks. After the children had their experiences with the shapes, they participated in the shape sorting task, where they were asked to sort shapes by which ones were "real" and which ones were "fake." Fifty one of the children returned in a week to perform the shape sorting task again. It was found that the children who compared the shapes shown to their typical version (equilateral triangle) and relied on their basic perception of the shapes would sort those into the "real" pile, but sort the atypical version (isosceles triangle) into the "fake" pile. Those who looked at the more abstract, geometric concepts and characteristics of the shapes sorted them into the "real" piles. It was revealed that different pedagogy had a significant effect in how children accepted typical and atypical shapes (a triangle is a closed shape that has three sides and three angles) but not how they accepted non-valid shapes (three lines, where two connect to make angles and a space is left at the top). The guided play group was able to identify more typical and atypical shapes as "real." The didactic instruction group was able to identify more atypical shapes as "real" when compared to the free play group. The finding that the guided play group outperformed the other two groups, and that the free play group fared the worst suggests that appropriate scaffolding of shape identification and properties will help to facilitate geometric shape recognition. Appropriate scaffolding can be done through a guided play pedagogy, as free play does not allow for specific shape concepts to be discussed, and didactic instruction does not engage the children and allow them to explore the materials with the adult.

Research about different block play conditions was conducted by Ferrara, Hirsh-Pasek, Newcombe, Golinkoff, and Lam (2011). These researchers questioned if the context of block play significantly impacted the amount of spatial language that was used by parents and, in turn, their children. The participants selected for this study were 36 White 4.5-year-olds and thirty-six 4.5-5-year-olds, along with their middle-to upper-class parents. The parent-child dyads were randomly assigned to either a free play (play with blocks like you would at home), a guided play (follow these steps to build ____ from the blocks), or a preassembled play (glued block model to play with) group for 10 minutes. After the 10 minutes were completed, all dyads were assigned to the guided play condition for an additional ten minutes. The 20 minutes was video-recorded for later coding. The results show that parents in the guided play activity used significantly more spatial talk than those in free play or the preassembled conditions. It was also found that children in the free play condition used significantly less spatial talk than the other two conditions. This shows that the play context impacts the spatial words that are used by both parents and children. The authors tell us that children need guidance and feedback from parents or caregivers. Adults should provide children with explanations and support to scaffold their learning of spatial language and concepts.

Interventions

Interventions in the classroom are often key in helping to support the development of geometric and spatial concepts in preschool- and kindergarten-aged children. Bruce and Hawes (2015) studied an in-class intervention and its effect on students' mental rotation and spatial thinking. Their participants consisted of 42 students, aged four to eight, who were from lower socioeconomic backgrounds. Participants were a mix of cultures from an urban area where English was predominantly spoken. Data for both pretest and posttest were collected by using a 2D mental rotation task and a 3D mental rotation task. The 2D task was adapted from the CMTT, where students were asked to identify which of four figures presented would be the result of two mirrored shapes that were mentally rotated and joined. In the 3D task, students were asked to match a 3D shape to a rotated version. Over a four month period of time, qualitative data were also collected from students and teachers through the use of interviews, video-recordings, field notes, and focus group interviews. The classroom intervention that was used consisted of five parts. First, the teacher-research team met and the researcher provided current information on spatial reasoning. Second, the researcher introduced four different geometry tasks to the teacher. For the third part of the intervention, the teachers were to co-develop fourteen tasks that were similar to what the researcher had shown them. One teacher was to implement these tasks in her room and finally, the team would review and adjust the tasks. After these adjustments, the tasks were used in all classrooms as interventions. On both the 2D and 3D tasks, improvements were seen in all age groups from pre- to posttest. The researchers conclude that accelerated development of 2D and 3D mental rotation skills is possible in a short, four month time period, as the gains that the participants made would have been too noteworthy for natural development and is unlikely that of a test-retest effect.

Gesturing, along with the use of spatial terms and phrases, is an intervention that can be used to support the development of spatial skills in the preschool and kindergarten classroom. Ehrlich et al. (2006) looked at if there were specific training conditions other than just practice that would improve spatial reasoning. They also observed gestures in adults and children while they were speaking about spatial transformation problems. The participants in this study consisted of 62 predominantly Caucasian 5-year-olds from middle-to upper-class families in the Greater Chicago area. To begin, the children were given a pretest, which consisted of looking at one shape that was divided into two pieces. These two pieces were then split into 4 choices, which were either directly translated, diagonally translated, directly rotated, or diagonally rotated. The children were shown these 4 pieces on a card and then asked to match it to the solid, whole piece from a 2x2 array of objects. After the pretest, the children were given the WPPSI-R as a standardized intelligence test to control for vocabulary skills. One week later the children were assigned to one of three conditions. The first training condition was designed to let the children experience transforming spatial pieces by imagining the movement of the shape's pieces. The experimenter asked the child to look at pieces and to put them together in his or her mind. After waiting 5 seconds, the experimenter then asked the child to choose a card that the pieces would make when put together. In the second training condition, the experimenter moved the piece cards together so that the child could observe the movement and the shape that was created by putting the pieces together. The child was then asked to choose the shape that the pieces made, just as in the first training condition. The third training condition was the practice condition and was the same as the pretest and posttest. Following their condition, a week later the children returned for a posttest and were also asked a set of probing questions to elicit their thought process about solving the problems. Throughout the entire experiment, the children's gestures were also closely observed and coded. The results from this study revealed that boys and girls in the second training condition (observe movement) improved on the posttest. However, in the observe movement condition, there was a significant interaction between sex and the scores from pretest to posttest. The girls in the training condition improved their scores but the boys performed worse from pretest to posttest. Data from previous research studies helped the researchers to hypothesize that this may be because the boys already had an effective strategy that was interrupted by the instructions. The children also described their strategies to the researchers, referring to movement the most and often conveying the same strategy in speech and in gestures. The researchers found that gesturing about moving the pieces often times helped children to be correct in their answers, whereas speech was not always as dependable. The researchers suggest that teachers implement gesturing in their teaching as an intervention to help children develop spatial transformation skills.

Spatial interventions in the classroom can also be seen with the use of technology, specifically with the use of iPads. Hawes, Moss, Caswell, and Poliszczuk (2015) explored whether or not participation in a 2D mental rotation training program would help to improve spatial thinking. They gathered 61 children between the ages of six and eight from Toronto, Canada. These children were from a school that supported the use of technology and were from middle- to upper-class socioeconomic backgrounds. The neighborhood where they were from consisted of 55% ELL (English Language Learner) students. The interventions that Hawes and Moss et al. (2015) implemented were spatial games on the iPad that individualized themselves for children. Two of the three games involved identification and matching of 2D shapes with time limits. The last game involved a puzzle activity where children had to rotate pieces. To individualize themselves to the children, the games allowed the children to pick up on the level where they had left off. A control group was used and these children were allowed to play a literacy game in the iPad. Pre- and posttests were given to each participant. These assessed the near, intermediate, and far transfer of the participants' spatial skills. The results show that there were significant gains from pre-test to post-test from the children in the spatial group compared to those in the literacy group. Significant improvement on three out of the five tasks indicates that spatial training did have an effect on the children, although they struggled with 3D objects that were represented in 2D form. This suggests that technology (specifically iPads) in the form of spatial games can be used as an intervention in the classroom to help improve some spatial skills.

Möhring, Ramsook, Hirsh-Pasek, Golinkoff, and Newcombe (2016) investigated if children with better spatial skills were able to more accurately map pitch intervals. The researchers recruited 53 five to seven year olds with no musical training. Sixteen adult participants were also recruited for pitch matching purposes. Möhring et al. (2016) investigated the 5-to 7-year-olds' processing of various pitch intervals and their relation to spatial skills by having them participate in four different tasks. The first was a pitch matching task where children were familiarized with each pitch and where it was on a keyboard. The children were then asked to point to the keyboard marking that corresponded with the pitch that was played. The second task involved children being asked to locate a number on an unmarked number line. The third task was the CMTT, and the fourth task was the Woodcock Johnson III-R Vocabulary Task to assess children's expressive vocabulary. Parents of the participants were also asked how many hours per week their child spent playing with blocks and puzzles or participating in spatial activities at home. The results of this study show that children's accuracy at pitch matching was related to higher spatial skills. Results suggest that 5-year-olds are capable of mapping pitch intervals onto their spatial counterparts. This skill can rapidly develop between five to seven years of age. The researchers share that mapping pitch could be an intervention for those students who are struggling with spatial skills. It might be a different intelligence that could help children to gain more of an understanding of spatial concepts.

Mazes and maps can also be used as an intervention in increasing spatial skills. Jirout and Newcombe (2014) wondered if children would use maps to solve mazes and what factors would influence this. They also questioned if map use would help children to solve mazes more efficiently and if this was related to their spatial scaling skills. To find the answers to these questions, Jirout and Newcombe (2014) found 41 participants; 19 children four years of age and 22 children five years of age. These children were from a suburban middle-to upper-class background and were all English speaking. To begin the study, children were given four different 2D paper mazes, from easier to harder. They were also given a map to help solve each maze. The maps were given one at a time and consisted of a concrete-unscaled map, followed by a concrete-scaled map. The next two maps that were given to help solve the mazes were an abstract-unscaled map, followed by an abstract-scaled map. The concrete maps were essentially a copy of the maze with the correct path drawn in. The abstract maps did not have the lines of the maze represented, simply the correct path line drawn in. The unscaled maps were the same size as the associated maze and the scaled maps were a smaller version. The results of this study showed that the more difficult the maze, the less accurate the completion. When children used unscaled maps versus scaled maps, they completed the mazes faster. The children were also better able to complete the mazes when the maps had maze lines versus no maze lines. Children spent an average of about 10% of their completion time looking at the maps, with the range being from 2.6 to 10.2 seconds). The participants who used the maps more often had significantly higher scores than those who used the maps less. The authors suggest that children might benefit from doing game-like tasks that incorporate maps into them. This might help to improve children's ability in using maps and spatial scaling and skills in general.

The last intervention discussed investigated the benefits of storytelling in teaching geometry skills to kindergarteners. Casey, Erkut, Cedar, and Young (2008) conducted two studies, with the main goal of developing spatial reasoning skills using part-whole relationship problems. The participants in the first study were 155 half-day kindergarteners from a lower-to middle-class suburban Boston area. These participants were ethnically and racially diverse, and 60% were from a minority background. Thirty-one percent of these students qualified for free or reduced lunch. The second study's participants were sixty-three students in full-day kindergarten, with 81% being from a minority background and 74% receiving free or reduced school lunches. The intervention for both Study 1 and Study 2 was taken from a geometry book titled, *Tan and the Shape Changer* (Schiro, Casey, & Anderson, 2002). This book is from a better known mathematics series called '*Round the Rug Math: Adventures in Problem Solving* (Casey, Schiro, & Anderson, 2002). In this intervention, geometry skills start simple and become more complex; they build upon one another. The story used for the intervention in this study allowed children to explore the part-whole relationship between triangles, rectangles, and parallelograms. The activities involved using puppets, chants, movements, and poems to engage as many children as possible. Children were either given the story plus geometry intervention plus their regular mathematics instruction or only their regular instruction. All children were given a pre- and posttest of a part-whole relations task, which consisted of a near and a far transfer. The near transfer task was the Triangles subtest from the Kaufman K-ABC. This assessed part-whole relations. The far transfer task was a Tangram test that assessed children's ability to solve a wider range of part-whole problems. The only difference between Study 1 and Study 2 was the participants' socio-economic backgrounds. The results of the study show that girls improved significantly more than the boys with the interventions in place. The boys improved on the near transfer task regardless of if they were in the intervention or control group. The researchers suggest that for boys, open-ended play might be enough to build these skills but for girls, specific interventions might be necessary to teach these spatial skills. Although there were significant improvements on the near transfer task, there were no differences in the intervention versus control group in the far transfer geometry pre and posttest. Despite these data, the results still show that teaching part-whole relationships in the context of a story telling intervention in addition to a typical mathematics curriculum is beneficial to kindergarteners, specifically girls.

Professional development

Professional development is key in allowing teachers to learn how to support their students with the development of geometric and spatial concepts in the classroom. Brendefur, Strother, Thiede, Lane, and Surges-Prokop (2013) initiated a professional development study to help educators improve their overall mathematics skills. Part of the skills that the researchers looked at were spatial relationships (spatial visualization, orientation, and relations) in the preschool classroom. Brendefur et al. (2013) recruited six Head Start centers, separating them into four treatment groups and two control groups. A total of 24 teachers participated, with educations ranging from a High School diploma to a Master's Degree. The students at the participating centers totaled 111 and the average age was 4.6-years-old. All students were below the poverty line and 23% were English Language Learners. The pre- and posttest that was used for each student was the Prekindergarten-Primary Screener for Mathematics (PK-PSM). This was administered in late September and early October and then again in late March and early April. The full day professional development that the teachers attended provided 8 hours' worth of activities that helped to develop their understanding and skills in number context, measurement, and spatial relationships. Teachers were given materials for students to engage with (in either small or large group context) and were then asked to return to a follow-up professional development a few months later. During this follow up, the teachers were re-taught ideas that were previously discussed and were able to ask questions about the materials and how to better implement them. The results from this 6-month study indicate that the control and treatment groups' scores on the PK-PSM did not differ on the pretest. However, the treatment groups' posttest scores on the measurement and spatial reasoning section of the PK-PSM improved significantly. The professional development along with the activities provided for the classroom had statistically significant effects on the students' overall mathematics knowledge, including their spatial relationship skills.

Summary of Data Gathered

This literature review discusses different ways that preschool- and kindergarten-aged children can develop geometric and spatial concepts. An important way in which children develop geometric and spatial concepts is through the type of talk and play that is in their environments. Parents and teachers who use more spatial language and give their children opportunities for spatial play tend to have children who develop a deeper language (Pruden et al., 2011; Ramani et al., 2014) and understanding of spatial concepts (Jirout & Newcombe, 2015; Levine et al., 2012). Allowing children to mentally and manually rotate 2D and 3D objects also allows for the development of spatial skills (Frick et al., 2013; Hawes & LeFevre et al., 2015). Ping et al. (2011) includes gesturing along with the rotation process to help benefit students. We learned that rotation abilities typically increase with age, but that the more training that is available for the children, the more their skills will develop. Lastly, giving children multiple experiences with spatial reasoning activities will help to develop their spatial skills. The more that children explore and investigate geometric figures (Tian & Huang, 2009), blocks (Verdine, Golinkoff, Hirsh-Pasek, Newcombe, Filipowicz, et al., 2014), and mental folding tasks (Harris et al., 2013), the more likely their geometric and spatial skills will develop.

This review also discusses ways that teachers can support the development of geometric and spatial concepts in the classroom. Simply exposing children to shapes in a variety of ways can help to solidify their basic geometric knowledge and shape learning (Resnick et al., 2016). A teacher's choice in pedagogy is also one of the most important techniques for allowing children to explore geometric and spatial concepts in the classroom. A guided play approach results in the scaffolding of shape identification and properties (Fisher et al., 2013) and more spatial language (Ferrara et al., 2011). This review also discusses several interventions that can be done in the classroom to help children's geometric and spatial abilities develop. Activities from teachers implementing classroom interventions to gesturing while communicating to their students, to using iPads, music, mazes, and storytelling will help to solidify these concepts in the classroom.

Chapter III: Conclusions and Recommendations

I chose the topic of geometric and spatial concepts to learn about the development of these concepts and how teachers can support them in their classrooms. These concepts are often ignored in the early childhood classroom but carry many developmental benefits across the mathematics field. Teachers need to understand the ways that geometric and spatial concepts develop so that they can intentionally implement activities and interventions in their classrooms.

My first research question targeted the development of geometric and spatial concepts in preschool- and kindergarten-aged children, both in the classroom and in other settings. I found that the development of these skills can occur in multiple ways. Allowing children to listen to and participate in spatial talk will increase their skills. When children are given spatial toys to play with, such as blocks, puzzles, and other geometric figures, their skills in this area are also likely to increase. Introducing the idea of mentally and manually rotating 2D and 3D objects, along with gesturing about these movements is also a way that these skills can develop.

My second research question asks what teachers can do to support the development of geometric and spatial concepts in the classroom. I found that exposing children to a variety of shapes and definitions can help to solidify their basic geometric knowledge and shape learning. A guided play approach in pedagogy is also the best choice for allowing students to interact with the concepts and to explore them with the teacher present. Implementing classroom interventions that are multi-modal is a way to support geometric and spatial concepts in the classroom. Providing professional development for educators is also a way to support the development of these concepts.

In this chapter, I identify and synthesize the insights from my literature review. I present recommendations to colleagues and other professionals in the early childhood field, along with how educational policies should be impacted. Finally, I discuss future research that needs to be done to help geometric and spatial concepts become more developed and researched topics.

Discussion of Literature Review

When I asked my research questions about geometric and spatial concepts, I intended to find thorough answers. I found a variety of articles that helped me to understand how and when these skills develop and what influences them in preschool- and kindergarten-aged children. I also found what supports teachers can implement in their classroom to help geometric and spatial skills develop.

The research shows that geometric and spatial skills can be developed when given exposure to the proper environment and materials. The findings from Chapter II suggest that the development of these skills can and does occur at the preschool and kindergarten level. According to Frick et al. (2013), spatial skills of 2D and 3D mental rotation development greatly increases from the age of three to five years old. This research and the research that examines how geometric and spatial skills develop points to children being capable of understanding and implementing these skills at a young age. This implies that teachers need to be aware of what children in their classroom are capable of doing, making sure to set high expectations for them in regards to these skills. This also suggests that teachers need to be aware of the specific concepts that are associated with this development so they are able to integrate them throughout their days and in their learning centers.

The research from Chapter II also indicates that spatial talk and play have a great influence on the development of geometric and spatial concepts in the early years. The findings from Pruden et al. (2011) tell us that the more spatial language that parents use, the more their child will use. This, in turn, helped them to score better on spatial tasks. This shows that parents, caregivers, and teachers should be aware of the vocabulary that they introduce to their children, trying to incorporate as many correct and accurate spatial terms as they can. The research investigating spatial play points to this type of play being positively associated with spatial skills. This indicates that the type of play, along with the frequency and quality that children are exposed to, affects their spatial skills. Children whose play more often involves geometric and spatial skill development tend to have a better understanding of these concepts (Jirout & Newcombe, 2015; Levine et al., 2012), develop deeper language skills (Pruden et al., 2011; Ramani et al., 2014), and possibly have a better chance at increasing their overall mathematical performance (Pruden et al., 2011).

Early childhood educators must view geometric and spatial concepts as important building blocks in the mathematics world. From the studies on how teachers can support the development of these concepts in the classroom, the research points to the significance of teachers using a guided play approach and intentional teaching in their classrooms. This suggests that teachers adopt an intentional, guided play pedagogy in the classroom. A guided play approach allows the students and teachers to learn alongside each other. The teacher asks questions and has discussions with the students to scaffold their learning through an exploratory process. An intentional teacher makes sure that he or she not only plans for children to engage in a variety of concepts, but also follows through on those plans with fidelity. This also suggests that a variety of classroom interventions be used for the diverse population of students who are in the classrooms. Successful interventions include using more spatial language, gesturing while communicating (Ehrlich et al., 2011), and using iPads (Hawes, 2015), music (Möhring et al., 2016), mazes (Jirout & Newcombe, 2014), and storytelling (Casey et al., 2008) to help solidify geometric and spatial concepts. Lastly, the findings from the research suggest that teachers be provided with professional development. Teachers need to be able to collaborate and find effective tools and strategies that will work to help improve the geometric and spatial skills of the students in their classrooms.

Recommendations for Professionals

As a result of reading and synthesizing the research to answer my questions and to learn more about this topic, I have created several recommendations. These recommendations will assist in developing geometric and spatial concepts in preschool- and kindergarten-aged children. In this section, I list recommendations for early childhood teachers and also recommendations for educational policies.

Recommendations for Early Childhood Educators

1) *Early childhood educators should intentionally integrate more spatial talk and spatial play into their curriculum.* Teachers can have deep and engaging conversations with students to scaffold their learning about the spatial concepts that can be developed in the activity that is being done. Setting time aside at a large or small group and intentionally choosing words and language to teach would be beneficial to the development of language skills. Spatial play can be incorporated into the curriculum by bringing in puzzles, blocks, books, and other materials that support the development of geometric and spatial concepts.

2) *Early childhood educators should involve children in the process of rotating shapes.* This is a concept that I had never thought to do in my preschool classroom and I suspect other educators have not either. By allowing children to experience shapes from different angles and positions, teachers are helping to deepen children's knowledge of what these shapes' characteristics really are. Teachers are teaching them that 2D shapes can be rotated, translated, or moved and are still the same shape. By allowing them to manipulate and rotate 3D shapes, teachers are developing skills about faces, angles, sides, and bases.
3) *Early childhood educators should practice incorporating gestures into their teaching.* Teachers can do this by first observing their use of gestures. This can be done by video-recording a lesson, paying close attention to the use of gestures and how they affect the interactions between the teacher and the child. Teachers can also have discussions with their colleagues to make a plan for increasing the amount of gestures used. Teachers can plan what specific gestures they are going to use during a certain time of the lesson as well. Practicing in front of a mirror at home would be beneficial to observing specific actions that are being made and adjusting them accordingly.
4) *Early childhood educators should have a variety of geometric and spatial materials available at large group, small group, and free choice time.* Children need to explore and investigate geometric figures in order to learn about them. During large or small group, teachers can plan on incorporating specific materials, such as tangrams, pattern blocks and their frames, LEGOS, unit blocks, and various 3-D shape blocks to allow children to explore the spatial relationships they can make with them. Materials are needed in sufficient quantities, and at levels that range from easy to hard, allowing for

children to explore and to be individually challenged. Teachers could create a checklist of the materials available to students on a daily basis and then reflect on what else needs to be available.

5) *Early childhood educators should reflect on their personal pedagogy.* They need to look at how they teach and the effects that their teaching style has on their students. Teachers can video-record themselves and keep a reflective journal about the different styles that they have tried. Reflecting on how their students respond to these different styles would be beneficial in learning how to gear their teaching towards more of a guided play approach. Reading books, having discussions with colleagues, or attending professional developments about a guided play approach in early childhood would also be good ways to ease into this style of teaching.
6) *Early childhood educators should meet on a weekly or bi-weekly basis.* Teachers need time to collaborate and create interventions to be used in the classroom for large and small group and also one-on-one with students. Interventions should be discussed and adapted to each individual's classroom and students. Teacher groups should be given the time to share their outcomes of the interventions and to adjust future lessons as needed.

Recommendations for Educational Policies

1) *Educational policies should look at geometric and spatial concepts more closely in the standards.* The Preschool section of the *Iowa Early Learning Standards* (Early Childhood Iowa, 2012) looks at shapes and spatial reasoning as an area in their mathematics and science standards (Standard 12.3: Shapes and Spatial Reasoning). However, the benchmarks are very generic and could go deeper. I suggest that policy

makers review this standard and incorporate more than spatial talk/vocabulary, shape ID, and shape transformation to also include the rotation of objects, gesturing, and engagement in spatial play.

2) *Educational policies should require professional development around the concepts of geometric and spatial development.* Giving teachers the opportunity to learn and develop, specifically in the areas of geometric and spatial concepts, along with interventions that can be done in the classroom should be a mandatory requirement in school districts. As I stated in Chapter 1, teachers need to feel confident in their personal understanding of geometric and spatial concepts. If they are confident, then they will be better able to teach and integrate these concepts throughout the day. I would recommend that districts look at having one professional development each year, along with a follow up for teachers to collaborate.

Future Research

More research needs to be done on the topic of geometric and spatial concepts. In this section, I identify several areas of future research that would be beneficial in helping this field to develop.

In this field, there needs to be more basic research so that studies are more generalizable to a wider population. Many of the studies that I reviewed were with Caucasian students or families. Of these families, almost all of them spoke English as a main language. The socioeconomic status of more than half of the studies were either of middle or upper class. Few of the studies were done with a lower socioeconomic population. The studies that were reviewed should be replicated, changing participants to collect data for the different populations. This would help the data results to be applied to a wider variety of people.

There needs to be more research done in the specific age groups of preschool and kindergarten. While I was researching articles, I did not uncover a lot of recent research for preschool-aged children that dealt with geometric and spatial concepts. I had to expand my search to include kindergarten-aged children as well. More data needs to be collected on how preschool- aged children develop these concepts and how teachers can help to support them in the classroom. This research would help to solidify the findings that exist or to shed new light on what we do not know. It would certainly be helpful in developing this field of study.

Researching the relationship between geometric and spatial concepts and overall mathematics ability would also be beneficial in helping this field to grow. Knowing the impact that geometric and spatial skills has on mathematics ability might make not only researchers investigate this concept more, but also educational policy makers and early childhood professionals as well. Having research that could possibly support this relationship might also motivate teachers to be more intentional about integrating these concepts into the classroom.

Lastly, diving deeper into the research and looking at the interactions of how different geometric and spatial concepts develop would be beneficial data to collect. Knowing if spatial talk, play, and reasoning had a strong positive relationship would be valuable for current early childhood teachers. If there was an intervention that could be done that incorporated not only basic spatial concepts, but also mental or manual rotation, or intentional spatial talk, it would be more efficient to use that than an intervention that only touched on one aspect of geometric or spatial concepts.

Chapter IV: References

Bobis, J. (2008). Early spatial thinking and the development of number sense. *Australian Primary Mathematics Classroom, 13*(3), 4-9.

Brendefur, J., Strother, S., Thiede, K., Lane, C., & Surges-Prokop, M. J. (2013). A professional development program to improve math skills among preschool children in Head Start. *Early Childhood Education Journal, 41*, 187- 195. doi:10.1007/s10643-012-0543-8

Bruce, C., & Hawes, Z. (2015). The role of 2D and 3D mental rotation in mathematics for young children: What is it? Why does it matter? And what can we do about it? *ZDM Mathematics Education, 47*, 331-343. doi: 10.1007/s11858-014-0637-4

Casey, B., Erkut, S., Ceder, I., & Mercer Young, J. (2008). Use of storytelling context to improve girls' and boys' geometry skills in kindergarten. *Journal of Applied Developmental Psychology, 29*, 29-48. doi: 10.1016/j.appdev.2007.10.005

Casey, B., Schiro, M., & Anderson, K. (2002). *'Round the rug math: Adventures in problem solving*. Chicago: The Wright Group/ McGraw Hill.

Clements, D. H. (2004). Geometric and spatial thinking in early childhood education. In D. H. Clements, J. Sarama, & M. A. DiBaise (Eds.), *Engaging young children in mathematics: Standards for early childhood mathematics education* (pp. 267- 298). Mahwah, NJ: Lawrence Erlbaum Associates, Inc.

Clements, D. H., Swaminathan, S., Hannibal, M. A., & Sarama, J., (1999). Young children's concepts of shape. *Journal for Research in Mathematics Education, 30*(2), 192-212.

Cohrssen, C., Church, A., Ishimine, K., & Tayler, C. (2013). Playing with maths: Facilitating the learning in play-based learning. *Australasian Journal of Early Childhood, 38*(1), 95-99.

Copple, C., & Bredekamp, S. (Eds.). (2009). *Developmentally appropriate practice in early childhood programs serving children from birth through age 8* (3rd ed.). Washington, DC: National Association for the Education of Young Children.

Early Childhood Iowa. (2012). *Shapes and spatial reasoning* (Standard No. 12.3). Retrieved from https://www.educateiowa.gov/sites/files/ed/documents/IowaEarlyLearningStandards2012-Aug2013.pdf

Ehrlich, S., Levine, S., & Goldin-Meadow, S. (2006). The importance of gesture in children's spatial reasoning. *Developmental Psychology, 42*(6), 1259-1268. doi: 10.1037/0012-1649.42.6.1529

Ferrara, K., Hirsh-Pasek, K., Newcombe, N., Golinkoff, R., & Lam, W. (2011). Block talk: Spatial language during block play. *Mind, Brain, and Education, 5*(3). 143- 151.

Fisher, K., Hirsh-Pasek, K., Newcombe, N., & Golinkoff, R. (2013). Taking shape: Supporting preschoolers' acquisition of geometric knowledge through guided play. *Child Development, 84*(6), 1872- 1878. doi: 10.1111/cdev.12091

Frick, A., Hansen, M., & Newcombe, N. (2013). Development of mental rotation in 3- to 5-year-old children. *Cognitive Development, 28*, 386-399. doi: 10.1016/j.cogdev.2013.06.002

Ginsburg, H., Lee, J., & Boyd., J. (2008). Mathematics education for young children: What it is and how to promote it. *Social Policy Report, 22*(1), 3-22.

Harms, W. (2012 February 15). Puzzle play helps boost learning of important math- related skills. *States News Service*. Retrieved from http://sandhills.idm.oclc.org.proxy.lib.uni.edu/login?url=http://go.galegroup.com.proxy.lib.uni.edu/ps/i.do?p=AONE&sw=w&u=uni_rodit&v=2.1&it=r&id=GALE%7CA280257923&asid=60a0cbd82a6becd48a94d883faa0fb88

Harris, J., Newcombe, N., & Hirsh-Pasek, K. (2013). A new twist on studying the development of dynamic spatial transformations: Mental paper folding in young children. *Mind, Brain, and Education* *7*(1), 49-55.

Hawes, Z., LeFevre, J-A., Xu, C., & Bruce, C. (2015). Mental rotation with tangible three-dimensional objects: A new measure sensitive to developmental differences in 4- to 8-year- old children. *Mind, Brain, and Education, 9*(1), 10-18.

Hawes, Z., Moss, J., Caswell, B., & Poliszczuk, D. (2015). Effects of mental rotation training on children's spatial and mathematics performance: A randomized controlled study. *Trends in Neuroscience and Education, 4*, 60-68. doi:10.1016/j.tine.2015.05.001

Jirout, J., & Newcombe, N. (2014). Mazes and maps: Can young children find their way? *Mind, Brain, and Education, 8*(2), 89-96.

Jirout, J., & Newcombe, N. (2015). Building blocks for developing spatial skills: Evidence from a large, representative U.S. sample. *Psychological Science, 26*(3), 302-310. doi: 10.1177/0956797614563338

Jung, M., & Conderman, G. (2013). Intentional mathematics teaching in early childhood classrooms. *Childhood Education, 89*(3), 173-177. doi: 10.1080/00094056.2013.792689

La Paro, K., Hamre, B., Locasale-Crouch, J., Pianta, R., Bryant, D., Early, D., Clifford, R., Barbarin, O., Howes, C., & Curchinal, M. (2009). Quality in kindergarten classrooms: Observational evidence for the need to increase children's learning opportunities in early education classrooms. *Early Education and Development, 20*(4), 657-692. doi: 10.1080/10409280802541965

Levine, S. C., Huttenlocher, J., Taylor, A., & Langrock, A. (1999). Early sex differences in spatial ability. *Developmental Psychology, 35*, 940-949

Levine, S., Ratliff, K., Huttenlocher, J., & Cannon, J. (2012). Early puzzle play: A predictor of preschoolers' spatial transformation skill. *Developmental Psychology, 48*(2), 530-542. doi: 10.1037/a0025913

Möhring, W., Ramsook, K., Hirsh- Pasek, K., Golinkoff, R., & Newcombe, N. (2016). Where music meets space: Children's sensitivity to pitch intervals is related to their mental spatial transformation skills. *Cognition, 151*, 1-5. doi: 10.1016/j.cognition.2016.02.0160010-0277

National Association for the Education of Young Children & National Council of Teachers of Mathematics. (2010). *Early Childhood Mathematics: Promoting Good Beginnings*. Retrieved from https://www.naeyc.org/files/naeyc/file/positions/psmath.pdf

Newcombe, N. (2010). Picture this: Increasing math and science learning by improving spatial thinking. *American Educator, 34*(2), 29-35.

Ping, R., Ratliff, K., Hickey, E., & Levine, S. (2011). Using manual rotation and gesture to improve mental rotation in preschoolers. *Cognitive Science,* 459-464.

Pruden, S., Levine, S., & Huttenlocher, J. (2011). Children's spatial thinking: Does talk about the spatial world matter? *Developmental Science, 14*(6), 1417- 1430. doi: 10.1111/j.1467-7687.2011.01088.x

Ramani, G., Zippert, E., Schweitzer, S., & Pan, S. (2014). Preschool children's joint block building during a guided play activity. *Journal of Applied Developmental Psychology, 35*, 326- 336. doi: 10.1016/j.appdev.2014.05.0050193-3973

Resnick, I., Verdine, B., Golinkoff, R., & Hirsh-Pasek, K. (2016). Geometric toys in the attic: A corpus analysis of early exposure to geometric shapes. *Early Childhood Research Quarterly, 36*, 358-365. doi: 10.1016/j.ecresq.2016.01.007

Schiro, M., Casey, B., & Anderson, K. (2002). *Tan and the shape changer*. Chicago: The Wright Group/ McGraw Hill.

Sparks, S. (2013, May 15). Children's spatial skills seen as key to math learning. *Education Week*, pp. 8.

Tian, Z., & Huang, X. (2009). A study of children's spatial reasoning and quantitative reasoning abilities. *Journal of Mathematics Education, 2*(2), 80-93.

Verdine, B., Golinkoff, R., Hirsh-Pasek, K, & Newcombe, N. (2014). Finding the missing piece: Blocks, puzzles, and shapes fuel school readiness. *Trends in Neuroscience and Education, 3*, 7-13. doi: 10.1016/j.tine.2014.02.005

Verdine, B., Golinkoff, R., Hirsh-Pasek, K., Newcombe, N., Filipowicz, A., & Chang, A. (2014). Deconstructing building blocks: Preschoolers' spatial assembly performance relates to early mathematical skills. *Child Development, 85*(3), 1062-1076. doi: 10.1111/cdev.12165

Verdine, B. N., Lucca, K. R., Golinkoff, R. M., Newcombe, N. S., & Hirsh-Pasek, K. (2016). The shape of things: The origin of young children's knowledge of the names and properties of geometric forms. *The Journal of Cognition and Development, 17*(1), 142-161. doi: 10.1080/15248372.2015.1016610