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Developing Spatial Abilities in Young Children: Implications for Early Childhood Education

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Abstract

This paper reviewed studies related to children's spatial reasoning and skills that were conducted primarily after 1999. The specific areas in which children manifest their spatial reasoning and skills followed three main themes: spatial skills innate to young children, mediation strategies, and mapping. These central themes were elaborated by reviewing empirical studies, identifying spatial abilities and effective strategies to promote them in children, and highlighting the need for a broader understanding for training young children in spatial skills. The underlying purpose of the review is to maximize effort and attention to cultivating spatial skills in children who are likely to be the next generation of mathematicians and scientists. Implications for early childhood education and future research are provided.

Introduction

Spatial abilities have been shown to influence mathematical and scientific reasoning (Garden, 1993, Delgado & Prieto, 2004). However, spatial abilities are not taught or nurtured at schools nor are they used to identify talent for science and mathematics (Webb et al, 2007). The aim of this paper is threefold: (1) to review empirical studies on spatial abilities for young children from 2005 to 2013; (2) to identify the significance of spatial abilities and effective strategies that can be used to foster them in young children; and (3) to highlight the need for a broader understanding for teaching spatial reasoning abilities to young children.

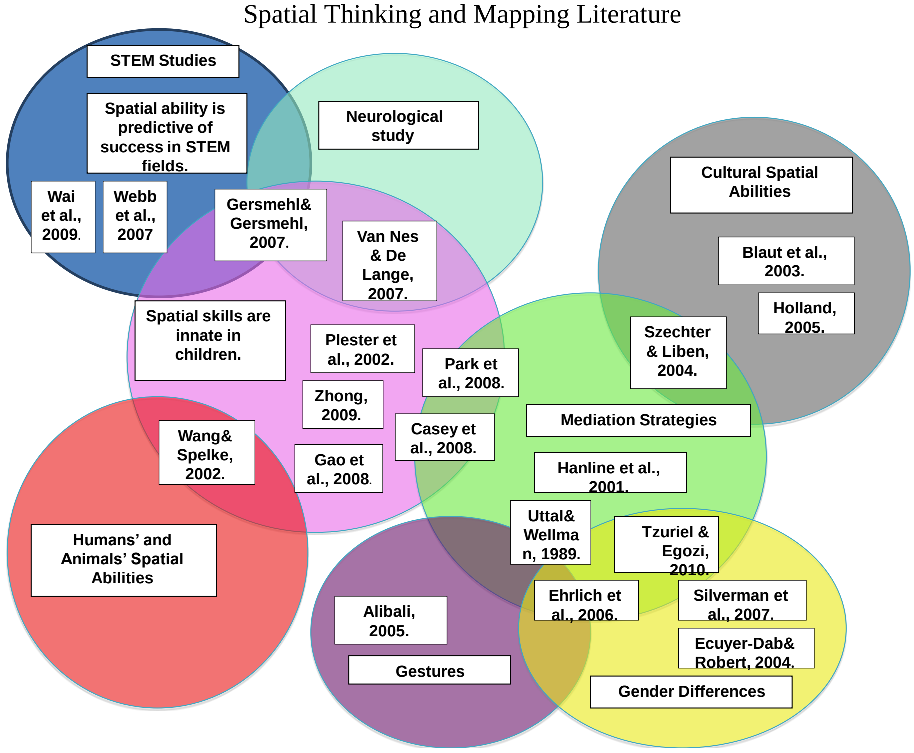
Research shows that spatial abilities are crucial to developing expertise in STEM and to identifying talent (Wai, Lubinski, and Benbow, 2009; and Webb, Lubinski and Benbow, 2007). For example in one study conducted by Wai, et al. (2009), a sample of 400, 000 9^{th} to 12^{th} graders was tracked over an 11-year period to see if there is any relationship between their initial spatial abilities and their future occupations. The findings showed that students with high spatialabilities went on to earn undergraduate, master, and doctorate degrees in STEM-related fields. In another study underscoring the importance of spatial abilities, Newcombe (2010) reported that research conducted on Albert Einstein's brain by a neuroscientist proved that "his parietal cortex, an area of the brain used for spatial and mathematical thinking, was unusually large and oddly configured"(p.29). In the reported study about Einstein, Witelson et al. (1999) pointed out that the weight of Einstein's brain was not different from the weight of controls, and that the large brain size has no correlation with intelligence. Thus, the parietal cortex findings predict intelligence, but more brain studies are needed to ascertain the relationship (Witelson, et al., 1999). It has been speculated, however, that the configuration of the area in the brain responsible for spatial thinking can be linked to Einstein'sexceptional spatial abilities. Watson and Cricks discovered the structure of DNA using three-dimensional spatial model for their existing flat images of the molecule (Watson & Crick, 1953). The findings of Witelson et al. (1999) and Watson & Crick (1953) point out the significant role spatial abilitiesplay in scientific fields.

This review primarily focuses on studies published after 1999 on the topic of spatial reasoning of young children. Although empirical studies related to practices in early childhood mathematics arelimited, the available literature is rich enough to stimulate research and discussion as well as extracting new practical applications of research findings. Our primary focus is to learn from what is there and make recommendations for future directions. In our search for empirical studies on spatial abilities, we reviewed available studies conducted in the United States and beyond. The studies gleaned for this review were synthesized and put on a diagram in order to find the different types of studies, the overlap that exists among them, as well as discern major themes underlying them.

Studies related to spatial reasoning gleaned from the literature are organized in groupings as shown in Figure 1 below. From this visual display, three major themes emerged: spatial skills innate to young children, mediation strategies, and mapping. Each of these themes is discussed in more detail next. Figure 1 represents the grouping of literature reviewed in this paper.

Figure 1

Spatial Thinking and Mapping Literature



Spatial thinking and mapping in young children: The chart above shows the literature reviewed in this article about young children.

Spatial Skill Innate to Young Children

The first major theme relates to spatial skills that are innate to children. In this section, this theme will be elaborated using the related studies in this grouping to support the claims of this theme.

Children's spatial reasoning abilities emerge earlier than their quantitative reasoning abilities because babies explore and understand space as soon as they are able to crawl. By preschool age, children show their special abilities (Lu, 2001). In a study conducted by Zhong(2009), a sample of 1,872 preschool to first grade children demonstrated high spatial reasoning ability. Navigation skills demonstrated by animals and used to move around and find their way in their surroundings are also innate in humans (Wang & Spelke, 2002). Because of this navigation interest, spatial reasoning develops at an early age. Gersmehl, & Gersmehl (2007) in their review concludedthat children's spatial reasoning is present and operative as early as three years (Nardini et al., 2006; Blaut et al, 2003 and Huttenlocher,et al, 1999). In support of this view,Blaut et al, (2003) showed that this spatial reasoning function is universal, ecological and cultural. Supporting the universality of spatial reasoning, Pellicano, Rhodes & Peters (2006) highlight that map-like modeling is used in nearly all cultures.Nardini et al., (2006) studied the spatial frames of reference in 3- to 6-year-old children and revealed that three year olds favored spatial representations that were not egocentric. Park, Chae & Boyd (2008) in their study of two boys proved that children categorized unit blocks as geometric shapes. In this study, the six-year-old boy used geometric terms in grouping blocks and recognized all triangles as triangles and used size to differentiate them. While the seven-year-old boy used familiar objects to describe blocks and referred to isosceles triangle as a roof-top, the scalene as a diamond, and a semi-circle as a half-wheel.

Van Es & de Lange (2007) pointed out that there are three main components in children's early spatial reasoning: spatial visualization, insight into shapes, and understanding of space.Studies conducted by Silverman & Peters (2007); Ehrlich, Levin, & Goldin-Meadow (2006); and Ecuyer-Dab & Robert (2004) stated that there is a gender difference favoring males in spatial abilities. In the aforementioned Silverman & Peters' (2007) study, it was stated that 35 out of the 40 countries in the study, men scored higher than women in three-dimensional mental rotation while women scored higher on object location memory. Ecuyer-Dab &Robert (2004) summarized the gender differences by highlighting that spatial differences among humans are high after puberty, and spatial differences favor males largely due to their hunting instincts. Gender differences, however, are not fixed and unchangeable. With training, both girls and boys improve their spatial abilities (Ehrlich et al., 2006). Tzuriel & Egozi (2010) discovered that training 6-year-olds' representations and transformation of visual-spatial information resulted in moderate gender differences in the experimental group while no change was observed in the control group.

Mapping

Mapping is the second theme highlighted in the literature, and deals with how children understand and use space. Children demonstrate their understanding of space in many ways, one of which is through map reading. For instance, in a study by Huttenlocher et al., (1999), three- to four-year-old children were able to use simple maps to get information about distance in a larger space.The children were first presented with an experimental condition consisting of a dot in a long thin rectangle and were then instructed to use that to find an object in a similar location in a much larger sandbox. All twenty five four-year-olds used maps accurately and so did the majority of the three-year-olds in the sample. In another study, Wang and Spelke's (2002) concluded that both animals and humans navigate space by using representations that are momentary. That is, the representations are situation-specific and serve the need of the moment rather than this being an enduring trait used across situations.

Furthermore, Wang and Spelke found that humans, much like insects such as ants, use view-dependent representations to recognize objects and places, and reorient themselves by analyzing the shape. Moreover, in another study demonstrating special ability in children, Plester, Richards, Blades, and Spencer (2002) conducted a series of three experiments with four- and five-year-old children's ability to use aerial photographs in identification and location tasks. Their results showed that the children demonstrated the ability to use the aerial photographs, and that the five-year-olds were more successful than the four-year-olds in their task performance. Plester et al.(2002) study underscored the fact that using photographs before using maps improved children's performance and success with maps.

Mediation Strategies

The third and final theme deals with mediation strategies of special abilities that children use. According to Donato and McCormick (1994), mediation is the vehicle responsible for cognitive change. As such, it can be manifested and produced in a variety of ways including textbook format, presentation of visual material, use of classroom discourse patterns, utilization of different occasions for second language interaction, and implementation of various types of direct instruction and other teacher assistance or scaffolding efforts.

Althoughmore empirical studies on mediation strategies of spatial abilities need to be conducted, the existing literature strongly shows that mediation strategies play a major role in nurturing spatial abilities in young children (Uttal & Cohen, 2012; Uttal, Meadow, Tipton, Hand,Alden, Warren & Newcomb, 2012; Szechter and Liben, 2004; Ehrlich et al., 2006; Park etal., 2008; Uttal and Wellman, 1989; and Casey et al., 2008).

In one of the studies that examined ways of fostering spatial abilities in children, Szechter and Liben (2004), examined the role parental strategies in reading play in promoting spatial abilities in their children. The specific strategies they investigated included reading, gestures, block building, and map use. Each of these areas is focused on in more detail next.

Reading strategies

Thethree parental reading strategies that Szechter and Liben (2004) investigated were labeled as constant referent on spatial-graphics, attention to depicted size, and verbal-gestural explanation or physical demonstration of zooming. In constant referenceto spatial-graphics, parents help children by identifying referential objects. They refer back to the object they encounter while reading. For instance, the parents might focus on the size of the object in different pages and focus on its meaning. In the second strategy which is attention to depicted size, parents pay attention to the size of the depiction. The researchers warn that this strategy is not advised to be used alone, and instead recommendusing it with others in order to avoid confusion. For the third strategy, parents demonstrate the meaning of zooming through gestures. Zooming, in this case, refers to making the pictures smaller or bigger to illustrate the concept of zooming.

The spatial graphic competence measure that Szechter and Liben (2004) used revealed that there was a significant correlation between parental behaviors and children's spatial graphic competence. The five-year-olds performed better than the three-year-olds. In addition to parental strategies, use of gestures was also a major area of study. Thus, it is to a discussion of this area that we turn next.

Gestures

Human beings use gestures to supplement and complement verbal expressions to communicate and represent meaning, especially when talking about spatial issues. The function of verbal-gestural explanations as an aid to spatial representationin children has been investigated and supported by a number of researchers (i.e., Goksum, Goldin-Meadow, Newcombe & Shipley, 2013; Sauter, Alman, Goldin-Meadow & Levine, 2012; Hostetter, Alibali & Bartholomew, 2011;Beilock & Goldin-Meadow, 2010; Ping & Goldin-Meadow, 2010; Ehrlich et al.,2006). To take one of the earlier studies in this area as an example, Ehrlich et al. (2006) examined both gestures used by children to explain their solutions to mental transformation problems, and potential gender differences in gestures between boys and girls. Their intervention had three conditions: (1) imagine movement, (2) observe movement and (3) practice movement. The findings indicated that boys performed better than girls on spatial transformation tasks, and the gestures used were not expressed in accompanying speech. Children who performed better on the spatial transformation task often referred to movement. Also, the boys gestured significantly more often about movement than girls and performed better on spatial transformation tasks than girls. This study also pointed out that even though boys outperformed girls before training, both boys and girls improved after training in their spatial rotation skills. Studies related to block building are discussed next.

Block Building

Block building has received limited attention by researchersinvestigating spatial reasoning strategies (Reifel & Greenfield, 1982; Park et al., 2008 and Hanline et al., 2001). Casey et al. (2008) contributed to our knowledge in this area by investigating three strategies of block building. The strategies were (1) storytelling combined with block building, (2) block building alone, and (3) unstructured block building. In all interventions, concepts covered were constructions, measuring, and creating one structure.In the storytellingcombined with block building condition, each construction had the story context. The findings of this study showed thatthe story telling context had more significant effects in block buildingand spatial visualization skills than the other two interventions. Both structured block building only and block building with a story had a significant effect on block design. However, the unstructured block building showed no significant effects at all. However, the three interventions did not have an effect on 3-dimensional mental rotation. Also, there were no gender differences for block building in all interventions. A similar finding about absence of gender differences was reported by Hanline et al. (2001). Common across the studies in this area (i.e., Hanline et al.& Kersh, Casey & Young, 2008) is the notion that complexity of block building develops with age, and that time involved in building blocks has positive effect on block construction. Use of maps is another manifestation of children's spatial abilities, and it is to a discussion of this strategy we turn next.

Use of Maps

Use of maps is another strategy recommended for facilitating spatial cognition, and it is an ability that young children are able to use to find a specific location. Piaget, Inhelder and Szeminska (1960) believed that maps could provide compelling insight into children's mental representations of space. Their claim was proven by research studies conducted in this area. For example, Uttal and Wellman (1989) investigated the impact of children's ability to read map on their understanding of space. Their findings showed that learning to read a map can significantly assist preschoolers in learning the spatial layout of a large scale space. This finding is corroborated by a study conducted by Siegler (1981).Blades & Spencer (2011) studied young children's ability to use a map to follow a route: a sample of 120 young children from the age of 4 to 6 year old. The children were divided into five groups and each was given a map of the maze that they are to follow the route in. The children were instructed to walk through the maze and had to make correct choices of where to go at different T-junctions in the maze. Half of the children were provided with landmarks placed at the junctions in the maze and on the map. The researchers found that all children except the youngest ones were able to perform the task and use the map successfully. Children's mental representation of space is also demonstrated by their understanding and utilization of space. Thus, it is to a discussion of how children understand and manipulate shapes that we discuss next.

Shapes

The final strategy highlighted in the literature is how children's spatial skills arereflected in their understanding and manipulation of shapes. Gagatsis et al., (2006) found that 20% of 4- to six-year-old children were able to conserve rectangles and transform them using both conservation and transformational dimensions. This study also showed that the older the kids the better they were at performing on conservation and transformation tasks. These findings run counter to Piaget's claim that the ability to conserve in children occurs later than age 7. Battista and Clements (1999) used Van Hiele's theory of describing children's thinking and discovered that there is an emerging level before level 1 of Van Hiele's levels which he labeled as a precognition level. Clements (2004) observed that children's geometric development confirms his perspective on developmental progression of children'sunderstanding and composition of shapes. In this study, students demonstrated the first four developmental progression levels in children's composition of shapes (pre-composer, piece assembler, picture maker, and shape composer). Clements and Sarama (2009) hypothesized the learning trajectories for shapes that need to be tested in more investigations. Moreover, Harris, Newcombe and Hirsh-Pasek (2013) utilized a test of mental folding in their study of 180 children between 4 and 7 years of age. They found that mental folding which is used to identify, represent and manipulate shapes appears in children around age 5 and a half. Based on their finding, Harris et al. suggested that preschool and kindergarten programs could nurture spatial transformation skills including mental folding.

Conclusion

The literature reviewed in this article highlights important factors in developing spatial abilities of young children. These factors are (1) the role played by spatial abilities in STEM fields (2) children's innate spatial abilities from different cultures that can be developed (3) limited strategies used in developing spatial skills. The literature proposes four purposeful activities: reading with attention to spatial graphics, encouraging use of gestures in explaining space, contextual block playing, and use of maps in learning more about space. Research-based activities that respond to these recommendations need to be designed and tested to give more support to the literature.Clements & Sarama (2009) developed a theory that gives basis for developmentally appropriate activities that can be designed. Also, testing this theory can deepen our understanding of how children develop cognitively and spatially.

A primary implication of this study for early childhood practitioners to first recognize the fact that spatial reasoning fosters quantitative reasoning in young children and then to implement age-appropriate strategies to promote spatial abilities and skills in young children. Young children who are exposed to a rich and stimulating environment in the realm of spatial abilities would certainly lay a strong foundation to nurturing mathematical understanding. The meta analysis by Uttal eta al. (2012) further show that spatial thinking skills are moldable, and that early childhood teachers and trainers could and should start molding and training the young minds in spatial thinking skills. In terms of recommendation for future research, researchers need to investigate further relevant spatial strategies for young children and the most effective ways of instilling them in children.

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