Cogent Education

ISSN: (Print) (Online) Journal homepage: https://www.tandfonline.com/loi/oaed20

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To cite this article: Zaid Alkouri | (2022) Developing spatial abilities in young children: Implications for early childhood education, Cogent Education, 9:1, 2083471, DOI: 10.1080/2331186X.2022.2083471

To link to this article: https://doi.org/10.1080/2331186X.2022.2083471

Published online: 02 Jun 2022.

Alkouri, *Cogent Education* (2022), 9: 2083471
https://doi.org/10.1080/2331186X.2022.2083471

cogent education

STUDENT LEARNING, CHILDHOOD & VOICES | REVIEW ARTICLE

Developing spatial abilities in young children: Implications for early childhood education

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Received: 19 July 2021
Accepted: 25 May 2022

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Reviewing editor:
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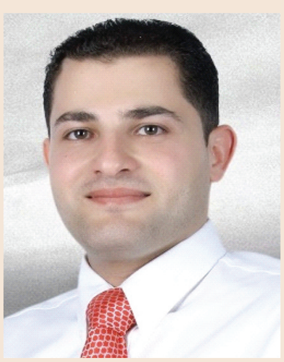
Abstract: Spatial ability is a form of intelligence where a person demonstrates the capacity to mentally generate, transform, and rotate a visual image and thus understand and recall spatial relationships between real and imagined objects. The aim of this paper is three-fold: (1) to review related empirical studies on spatial abilities for young children from 1999 to 2022; (2) to underscore the significance of spatial abilities and effective strategies that can be used to foster in young children; and (3) to highlight the need for a broader understanding for teaching spatial reasoning abilities to young children. A two-phase literature review was conducted. The first focused on grouping studies according to the common areas they dealt with. The second focused on identifying major themes. Three major themes emerged from the literature: spatial skills innate to young children, children's perception of space, and their mediation strategies. There are two implications of these themes for early childhood practitioners. The first is for them to recognize the importance of spatial reasoning for fostering quantitative reasoning in young children. The second is to implement age-appropriate strategies to foster spatial abilities and skills in young children. Recommendations for further studies are also provided.



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Zaid Alkouri is an Assistant Professor at Jerash University. He obtained his Ed.D. in Curriculum & Instruction with a focus on Early Childhood Education from The College of Education, University of Northern Iowa, USA. His research areas include early childhood development, early childhood education, cognitive development, psychology of the child, STEM areas during the childhood years, early childhood curriculum, and teacher professional development.

PUBLIC INTEREST STATEMENT

Spatial ability is a form of intelligence where children demonstrate the capacity to mentally generate, transform, and rotate a visual image and thus understand and recall spatial relationships between real and imagined objects. Understanding spatial development is important to educators, especially early childhood practitioners, because spatial skills are a central aspect of evolutionary adaptation and a key component of human intellect. In addition, spatial abilities have practical significance, both in everyday life and in facilitating the learning of science, technology, engineering, and mathematics. Spatial abilities have been shown to influence mathematical and scientific reasoning. Hence, spatial abilities need to be deliberately and planfully taught and nurtured in schools and at the earliest age possible. In this paper, empirical studies published from 199-2022 on spatial abilities for young children are reviewed to underscore the significance of spatial abilities and effective strategies that can be used to foster in for young children, and to highlight the need for a broader understanding for teaching spatial reasoning abilities to young children.

Subjects: Educational Research; Education Studies; Sociology of Education; Childhood; Educational Psychology

Keywords: Spatial; skills; young children; early childhood; STEM; reasoning

1. Introduction

Spatial ability is a form of intelligence where young children demonstrate the capacity to mentally generate, transform, and rotate a visual image. (Geary, 2022). This capacity helps them to understand and recall spatial relationships between real and imagined objects (Gifford et al., 2022). Understanding spatial development is important because spatial skills are a central aspect of evolutionary adaptation and a key component of human intellect. Furthermore, they have practical significance, both in everyday life and in facilitating the learning of science, technology, engineering, and mathematics. (Bokhove & Redhead, 2022; Newcombe et al., 2013). Spatial abilities have been shown to influence mathematical and scientific reasoning (Delgado & Prieto, 2004; Gardner, 1993; Johnson et al., 2022). However, spatial abilities are not taught or nurtured at schools nor are they used to identify talent for science and mathematics (Gifford et al., 2022; Webb et al., 2007).

In addition to this introduction, there are seven sections. They include the purpose of the study, literature review, findings, how the literature review is conducted, discussion, conclusion and implications. We turn to the purpose of the study next.

2. The purpose of the study

The aim of this paper is threefold: (1) to review empirical studies on spatial abilities for young children from 2005 to 2022; (2) to identify the significance of spatial abilities for young children; and (3) to highlight the need for a broader understanding for teaching spatial reasoning abilities to young children.

Research (i.e., Bokhove & Redhead, 2022; Gifford et al., 2022; Wai et al., 2009; Webb et al., 2007) shows that spatial abilities are crucial to developing expertise to identify talent and in many areas, especially STEM. 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 11 years to see if there is any relationship between their initial spatial abilities and their future occupations. The findings showed that students with high spatial abilities went on to earn undergraduate, master's, 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's exceptional spatial abilities. Watson and Cricks discovered the structure of DNA using a three-dimensional spatial model for their existing flat images of the molecule (Geary, 2022; Watson & Crick, 1953). The findings of Witelson et al. (1999) and Watson and Crick (1953) point out the significant role spatial abilities play in scientific fields. The literature review is what we turn our attention to next.

3. Literature review

This review primarily focuses on studies published after 1999 on the topic of spatial reasoning in young children. Although empirical studies related to practices in early childhood mathematics are limited, the available literature is rich enough to stimulate research and discussion as well as extract 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 to find the different types of studies, the overlap that exists among them, as well as discern the major themes underlying them.

Study results revealed three main themes related to spatial reasoning: spatial skills innate to young children, children's perception of space, and their mediation strategies. Findings related to each of these themes are discussed in more detail in the next section.

4. Findings

4.1. Spatial skills 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 on 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 can crawl. By preschool age, children show their special abilities (Geary, 2022; 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 and Gersmehl (2007) in their review concluded that children's spatial reasoning is present and operative as early as three years (Blaut et al., 2003; Huttenlocher et al., 1999; Nardini et al., 2006). 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 et al. (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 et al. (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 the isosceles triangle as a roof-top, the scalene as a diamond, and a semi-circle as a half-wheel.

Van Nes and 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 et al. (2007), Ehrlich et al. (2006), and Ecuyer-Dab and Robert (2004) stated that there is a gender difference favoring males in spatial abilities. In the aforementioned Silverman et al. (2007) study, it was stated that in 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 and 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 and 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. The findings of the next grouping deal with children's perception of space.

4.2. Children's perception of space

Children's perception of space is the second theme highlighted in the literature and deals with how children understand and use space. Children demonstrate their perception of space in many ways, one of which is through map reading that will be elaborated further among mediation strategies. 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 momentary representations. 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 (2002) 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 et al. (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 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. The Mediation strategies theme is discussed next.

4.3. Mediation strategies

The third and final theme deals with mediation strategies and special abilities that children use. According to Dinato and MacCormick (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.

Although more empirical studies on mediation strategies for 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; Sauter et al., 2012; Szechter & Liben, 2004; Ehrlich et al., 2006; Park et al., 2008; Uttal & Wellman, 1989; 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, map use, and shapes. Each of these areas is focused on in more detail next, beginning with reading strategies.

4.4. Reading strategies

The three parental reading strategies that Szechter and Liben (2004) investigated were labeled as a constant referent on spatial graphics, attention to depicted size, and verbal-gestural explanation or physical demonstration of zooming. In constant reference to 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 on 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 recommend using it with others t 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, the use of gestures was also a major area of study. Thus, it is to a discussion of this area that we turn next.

4.5. 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 representation in children has been investigated and supported by several researchers (i.e., Beilock & Goldin-Meadow, 2010; Ehrlich et al., 2006; Goksun et al., 2013; Hostetter et al., 2011; Ping & Goldin-Meadow, 2010; Sauter et al., 2012). 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 the 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.

4.6. Block building

Block building has received limited attention from researchers investigating spatial reasoning strategies (Hanline & Milton, 2001; Park et al., 2008). 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 storytelling combined with block building conditions, each construction had the story context. The findings of this study showed that the storytelling context had more significant effects on block building and 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 affect 3-dimensional mental rotation. Also, there were no gender differences for block building in all interventions. A similar finding of the absence of gender differences was reported by Hanline and Milton (2001). Common across the studies in this area (i.e., Hanline et al. & Kersh et al., 2008) is the notion that the complexity of block building develops with age, and that time involved in building blocks has a positive effect on block construction. The use of maps is another manifestation of children's spatial abilities, and it is to a discussion of this strategy we turn next.

4.7. Use of maps

The use of maps is another strategy recommended for facilitating spatial cognition. It is also an ability that young children can use to find a specific location. Piaget, Inhelder, and Szeminska (2013) 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 a 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 large-scale space. This finding is corroborated by a study conducted by Siegel (1981). Blades and 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 years 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.

4.8. Shapes

The final strategy highlighted in the literature is how children's spatial skills are reflected in their understanding and manipulation of shapes. Gagatsis, A., & Shiakalli, M. (2004) 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 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 (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 the developmental progression of children's understanding 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). Gagatsis, A., & Shiakalli, M(2004) hypothesized the learning trajectories for shapes that need to be tested in more investigations. Moreover, Harris et al. (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. (2013) suggested that preschool and kindergarten programs could nurture spatial transformation skills including mental folding. Next, we describe how the literature review was conducted.

4.9. How the literature review was conducted

As stated earlier, studies on children's spatial abilities, published between 2005 and 2022, were reviewed for this paper. Researcher's initial review was based solely on the publication order in the studies examined. The initial review showed that the studies belonged to the groupings of STEM, neurological studies, studies on cultural spatial abilities, children's spatial skills, human and animal spatial skills, gestures about space, mediation strategies children use in relation to their spatial abilities, and the gender differences in spatial abilities. T The researcher looked for some common themes associated with children's spatial abilities. This further review revealed three major themes: *spatial skills innate to young children, children's perception of space*, and *their mediation strategies*. The discussion of the study's findings is focused on in the next section.

5. Discussion

The review of empirical studies showed that as a central aspect of evolutionary adaptation, the spatial skills contribute to the facilitation of learning in science, technology, engineering, and mathematics (Newcombe et al., 2013). The spatial skills may be innate in children (Wang & Spelke, 2002): they show high levels of spatial abilities at a very young age (Johnson et al., 2022; Lu, 2001). Through spatial reasoning, children can use spatial visualization, they have the understanding of space, and they have insight into shapes (Bokhove & Redhead, 2022; Van Nes & De Lange, 2007).

The reviewed studies also indicated that children have various ways of demonstrating their perception of space. One is through their use of maps (Huttenlocher et al., 1999; Plester et al., 2002; Wang & Spelke, 2002) to accomplish tasks associated with space and location problems.

Another finding of the literature review was about the mediation strategies such as reading, gestures, block building, map use, and shapes to nurture spatial abilities in young children (Uttal & Cohen, 2012; Sauter et al., 2012; Szechter & Liben, 2004; Ehrlich et al., 2006; Park et al., 2008; Uttal & Wellman, 1989; Casey et al., 2008).

Reviewed studies (such as Clements & Sarama (2009) and Harris et al. (2013)) indicate that a better understanding of teaching spatial abilities to young children is needed.

6. Conclusion

The literature reviewed in this article highlights important factors in how spatial abilities develop in young children. These factors include the role played by spatial abilities in STEM fields, how to develop children's innate spatial abilities from different cultures, and the limited number of strategies that are used in developing spatial skills. This calls for expanding the repertoire of strategies among early childhood practitioners. Implications of the findings and recommendations for future studies are presented next.

6.1. Implications

A primary implication of this study for early childhood practitioners is to first recognize the fact that spatial reasoning fosters quantitative reasoning in young children. To build on the first implication, practitioners need to implement age-appropriate strategies to foster 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 for nurturing mathematical understanding. The meta-analysis by Uttal and Cohen (2012) shows that spatial thinking skills are moldable, and that early childhood teachers and trainers could and should start molding and training young minds in spatial thinking skills.

6.2. Recommendations

The literature proposes four purposeful activities: reading with attention to spatial graphics, encouraging the use of gestures in explaining space, contextual block playing, and the 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 and Sarama (2009) developed a theory that gives a basis for developmentally appropriate activities that can be designed. Also, testing this theory can deepen our understanding of how children develop cognitively and spatially. In terms of recommendations for future research, researchers need to investigate further relevant spatial strategies for young children and the most effective ways of instilling them in children.

Funding
The authors received no direct funding for this research.

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Disclosure statement
No potential conflict of interest was reported by the author(s).

Citation information
Cite this article as: Developing spatial abilities in young children: Implications for early childhood education, Zaid Alkouri, *Cogent Education* (2022), 9: 2083471.

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