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Review Article

Finding the missing piece: Blocks, puzzles, and shapes fuel school readiness ☆

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ABSTRACT

Experiences with spatial toys such as blocks, puzzles, and shape games, and the spatial words and gestures they evoke from adults, have a significant influence on the early development of spatial skills. Spatial skills are important for success in science, technology, engineering, and mathematics (STEM) fields [77] (e.g., Wai, Lubinski, Benbow and Steiger, 2010), and are related to early mathematics performance [48] (Mix and Cheng, 2012), as early as age 3 [73] (Verdine, Golinkoff et al., in press). This paper focuses on the effects of early spatial experiences and their impacts on school readiness, discusses factors that influence the amount and quality of spatial play, and suggests methods for providing a "spatial education" prior to school entry.

Contents

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1. Early experiences with blocks, puzzles, and shapes play an important role in school readiness

Spatial skills, or the ability to mentally manipulate information about objects in the environment and the spaces we inhabit (see [70]), are essential for everyday functioning. However, the teaching of these skills is largely ignored in formal school settings [13] and, perhaps as a result, many people seem to believe that spatial skills are not "teachable." To the contrary, research indicates that spatial skills are quite malleable (e.g., [70]). This paper focuses on why it is so important to provide a "spatial education" to young children, discusses materials and methods for delivering that education, and makes recommendations about how to deliver spatial training to improve school readiness for science, technology, engineering, and mathematics (STEM) subjects.

2. Why do spatial skills matter?

Experiences such as efficiently packing a car trunk, using a mall map to find a store, and cutting equal slices of pizza for a group of children all require spatial ability. These activities are mostly innocuous, low-stakes endeavors (except maybe dividing the pizza evenly!). However, a number of vitally important careers require strong spatial skills (e.g., air traffic control) and errors could be disastrous in many common spatial challenges, for example, inaccurately following a diagram to install a child's car seat. Many spatial skills are also key in preparing students for the STEM disciplines [53]. Studies have shown that spatial competence in grade school has significant consequences for student trajectories in STEM fields through high school and adulthood (e.g., [38,76,77]). For example, Fig. 1 is adapted from [76] and shows the average spatial skills of individuals in grades 9–12 with their reported career fields 11 years later. As can be seen, the high school spatial abilities for those in STEM careers are, on average, much higher than students with careers in other fields.

This relation between STEM success and spatial skills is due, at least in part, to the reliance of the STEM disciplines on spatial representations such as diagrams, maps, blueprints, and timelines. These representations help illustrate complex, multi-step biological processes (e.g., DNA replication and cell division), complicated systems (e.g., gravity interactions between the earth, the moon, and a spacecraft), and timelines occurring on unfamiliar timescales (e.g., geologic time). Being able to generate, interpret, and visualize changes to these representations helps master complex concepts and generate new ideas.

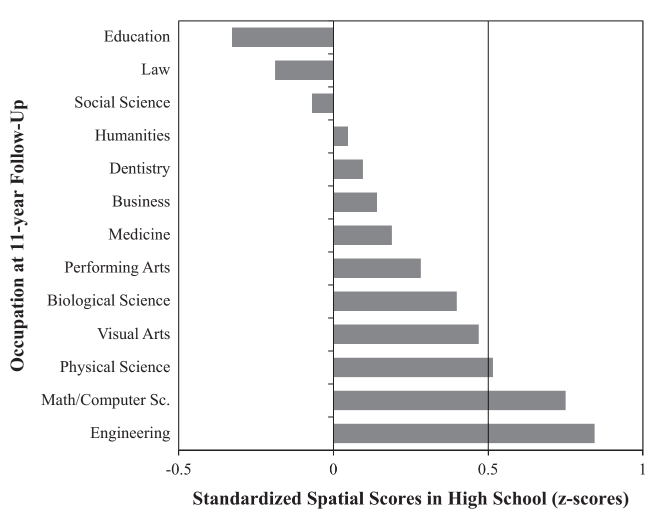

Fig. 1. Spatial Scores in 9th–12th Grade and Reported Occupations 11 Years Later.

2.1. Links between spatial skills and mathematics performance

Another reason that spatial skills may be vitally important for success in scientific disciplines is their relationship to mathematical skills (e.g., [48]). Links between spatial and mathematical skills have been firmly established in school-age children and adults (e.g., [2,11,33,37,62]). Clements and Sarama [13] posit that, at its core, mathematics involves spatial thinking and Mix and Cheng [48] concluded that, "The relation between spatial ability and mathematics is so well established that it no longer makes sense to ask whether they are related." (p. 206).

We still need to know more about causal relations between these skills and the direction of the effects. However, there is growing evidence that the relationship between spatial and mathematical abilities emerges quite early. Verdine et al. [73] found relations between spatial and mathematical skills at age 3, when children first begin to count and do simple addition and subtraction. Indeed, Verdine et al. [74] were able to predict over 70% of the variability in mathematics performance at age 4 using only measures of spatial skill at age 3 and 4 with executive function measures at age 4. Spatial skill uniquely predicted 27% of the variability in mathematics even after accounting for executive function. This line of research is also yielding evidence that spatial assembly skills at age 3 continue to predict mathematical skills at age 5 [21]. Other research investigating the connection between spatial and mathematical skills in older children and adults (e.g., [78,4]) show that the relationship appears to grow in strength with additional time. Although not conclusive evidence of causality, increasingly high correlations are consistent with spatial skills providing a foundation for mathematics learning.

These early links between spatial and mathematical skills are intriguing; in later written mathematics and when problem solving can be assisted by diagramming, spatial skills have a more intuitive role in supporting mathematics. How can we explain earlier links between spatial and mathematical skills? One potential mechanism is that mental models of number may be grounded in spatial representations. Research shows that the number line appears to be invoked to solve approximate calculation and estimation problems (e.g., [5]). To apprehend that numbers farther down the number line are bigger than those at the beginning, children have to spatially represent the ordering (see Fig. 2). Gunderson et al. [33], in the first of two longitudinal datasets, found that children's spatial skill at the start of 1st and 2nd grade predicted number line improvement during the school year. In the second dataset, 5-year-olds' spatial skill predicted their approximate symbolic calculation skills at age 8, mediated by their linear number line knowledge at age 6. Ramani et al. [61] also indicates a role for spatial skills in mathematical domains by showing that a board game based on the linear number line can improve number line estimation, magnitude comparison, numeral identification, and counting among lower-income children. Children who develop better spatial representations of number earlier may be able to build on this knowledge base to learn other numerical concepts (e.g., place value; [49]). Further evidence of a spatial and mathematical link comes from neuroscientific evidence that suggests that similar areas in the brain, specifically the intraparietal sulcus [1] and the neighboring angular gyrus [29], respond to

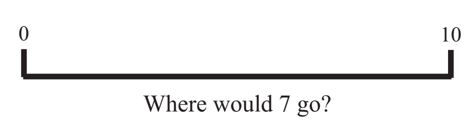

Fig. 2. A typical number line estimation task consists of trials asking participants to locate a number on a line (e.g., 7) with other numbers anchoring each end of the line (e.g., 0 and 10) and no marks in between.