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The Relationship between Spatial and Linguistic Intelligence with Mathematical Problem Solving Abilities

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

There is emerging consensus that spatial intelligence and linguistic intelligence play fundamental roles in how individuals comprehend, express, approach, and solve mathematical problems. However, the underlying nature of this relationship remains challenging to grasp. Questions persist regarding how, why, and under what conditions spatial and linguistic intelligences are interrelated with mathematical problem-solving. This article addresses these questions through a literature review method, summarizing and synthesizing research from the fields of educational psychology and neuroscience. Findings indicate that spatial intelligence is associated with mathematical problem-solving. However, not all areas of mathematics have a consistent and strong relationship with spatial intelligence. In the findings of this article, a strong and consistent relationship between spatial intelligence and mathematical problem solving was found in areas such as geometry and algebra. As for linguistic intelligence, a fairly consistent relationship with mathematical problem

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solving ability was found. This may be because mathematical problem solving requires discursive skills, which are part of linguistic intelligence. The review concludes by considering the extent to which spatial and linguistic intelligence can be transferred to mathematical problem solving. Ultimately, this article aims to provide a more coherent and mechanistic explanation of the relationship between spatial and linguistic intelligences.

Keywords: Intelligence; spatial; linguistic; mathematical problem solving.

1. INTRODUCTION

One of the fundamental skills that students must possess in mathematics education is problem-solving ability. Problem-solving is the most effective concept for contextualizing and recontextualizing mathematical concepts, for operationalizing and transferring fundamental mathematical knowledge, and for ensuring continuous and meaningful learning. Therefore, the ability to solve mathematical problems plays a crucial role in achieving the goals of mathematics education in schools, as it equips students not only for learning within the school environment but also for facing challenges in society. However, in the context of school learning, teachers often express concerns about the relatively low problem-solving abilities of students. Various factors can influence this, including personal, instructional, and environmental factors. One personal factor that influences problem-solving ability is spatial intelligence. Based on research conducted by several scholars, including Turğut and Yilmaz [1], Rabab'h and Arsaythamby [2], Verdine et al. [3], Hannafin et al. [4], and Oktaviana (2016), it is evident that spatial ability has a positive correlation with students' problem-solving capabilities.

The process of mathematical problem-solving heavily relies on one's ability to think critically, and this ability is inherently tied to an individual's intelligence. In essence, human beings are created with inherent differences, including in the realm of intelligence, where each person possesses a unique inclination towards one form of intelligence over others. Although these intelligences vary from one individual to another, no single intelligence is considered superior or more important than the others; they are all equal [5,6]. All forms of intelligence are possessed by humans in varying degrees. While genetic factors play a role in a child's intelligence, it is crucial to emphasize that genetic factors are not the sole determinants of one's intelligence. With training and practice, individuals can cultivate and develop their intelligence optimally, as genetic factors are not the sole influencers of an individual's intelligence. Through consistent effort, one can harness their innate intelligence strengths and mitigate weaknesses. These diverse intelligences can collaborate to facilitate various human activities. A single activity may require the engagement of more than one form of intelligence, and a single intelligence can be applied across multiple domains [7].

The development of studies on intelligence gained popularity with Howard Gardner (1983), who conducted extensive research over several years and concluded that all humans possess intelligence, or in other words, there is no such thing as an unintelligent person. This paradigm challenged the earlier dichotomous theory of intelligence and unintelligence. Gardner also opposed the notion of "intelligence" solely in terms of IQ (intellectual quotient), which only referred to three types of intelligence: logical-mathematical, linguistic, and spatial. Howard Gardner introduced the term "multiple intelligences," which he later developed into a theory through complex research, involving anthropology, cognitive psychology, developmental psychology, psychometrics, biographical studies, animal physiology, and neuroanatomy (Armstrong, 1993). At its inception, the concept of multiple intelligences, as proposed by Gardner, included seven variants of intelligence: linguistic intelligence, logical-mathematical intelligence, interpersonal intelligence, intrapersonal intelligence, musical intelligence, spatial intelligence, and kinesthetic intelligence. Subsequently, in line with the progression of his research, in the 1990s, Howard Gardner added two more intelligences: naturalist intelligence and existential intelligence.

Currently, there is a renewed interest in the development of studies related to various types of intelligence, and these studies have given rise to another form of intelligence known as financial intelligence. The reason why financial intelligence is not categorized as a talent is that it can be learned, honed, perfected, and continuously sharpened, much like the nine intelligences mentioned earlier. The theory of financial intelligence is now more recognized in the banking sector, where it refers to the ability to apply data analysis, machine learning, and other forms of artificial intelligence in financial services, such as banking, insurance, and investment management. However, research regarding the integration of the theory of financial intelligence into the field of education, particularly its specific role in the learning process, has not yet been extensively explored.

In connection with students' abilities in mathematical problem-solving, several studies have indicated that there are certain intelligences closely related to the state of the art in mathematics and can influence students in solving mathematical problems. These intelligences include logical-mathematical intelligence, spatial intelligence, and linguistic intelligence. Logical-mathematical intelligence is the closest intelligence to mathematics and is therefore highly essential in problem-solving. However, what's intriguing is the role of the other two intelligences, spatial and linguistic, which previous studies have shown can facilitate students in developing strong mathematical problem-solving abilities. According to a study conducted by Hawes and Ansari in [8], there are at least four main points that can serve as a foundation for understanding the relationship between spatial intelligence and mathematical proficiency. These four points are: Spatial representation of numbers, Neural co-processing, Spatial modeling, and Working memory. Hawes argues that these four points do not work in isolation but rather collaboratively enhance the connection between spatial intelligence and mathematics.

2. METHODS

Numerous studies have shown that numbers can be spatially represented. However, it is still not entirely clear to what extent spatial representation of numbers can have a positive impact on academic performance, particularly in mathematical problem-solving. Nevertheless, this provides some insight into how spatial intelligence and mathematical problem-solving may be interconnected. Furthermore, concerning neural co-processing, Hawes explains that the relationship between spatial and numerical aspects may occur because both rely on the same brain regions and employ similar neural computations. This assertion is based on neurological reviews. As for the third point regarding spatial modeling, it serves as the strongest foundation for explaining the relationship between spatial and numerical aspects among the four points, primarily because spatial modeling is frequently employed in mathematics.

Additionally, linguistic intelligence is another form of intelligence closely related to mathematics. According to Thomas Armstrong, linguistic intelligence involves the ability to manipulate language syntax or structure, phonology or the sound of language, semantics or the meaning of language, and pragmatic dimensions or practical language usage. Some of these uses include rhetoric (using language to persuade others to take specific actions), mnemonics (using language to remember information), explanation (using language to inform), and metalinguistics (using language to talk about language itself). Therefore, this intelligence is closely tied to language usage. According to Robertson and Graven [9], learner-centered education currently emphasizes the discursive skills of students, particularly in mathematics classes. Consequently, to enable students to maintain their mathematical thinking, verbal-linguistic intelligence is essential. This perspective underscores the importance of verbal-linguistic intelligence in learning mathematics.

This article aims to investigate the roles of spatial intelligence and linguistic intelligence in mathematical problem-solving. More specifically, it explores how spatial intelligence and linguistic intelligence can facilitate students' mathematical problem-solving abilities. The primary objective is to address the questions of whether these two intelligences are interrelated with mathematical problem-solving skills and why they can be linked to mathematical problem-solving abilities.

Why is this issue important? Because delving deeper into this matter can provide valuable insights for educators, especially those facing challenges in enhancing students' problem-solving abilities. It also helps us understand the positions of spatial and linguistic intelligence in relation to mathematical problem-solving. This information can serve as a basis for formulating instructional approaches that stimulate both spatial and linguistic intelligences, ultimately leading to improvements in mathematical problem-solving skills.

3. RESULTS AND DISCUSSION

3.1 How can Spatial Intelligence Influence Problem-solving Abilities?

When examining the characteristics of spatial intelligence, many argue that it is closely related to mathematical problem-solving, particularly in the context of geometry. Therefore, in this section, we will elaborate on the role of spatial intelligence in mathematical thinking. More specifically, how spatial intelligence can impact the problem-solving abilities of students. The relationship between spatial intelligence and mathematics is no longer in question, but what requires in-depth study is how they can interrelate so that this relationship can be fully utilized by educators [10]. There has been over a century of research examining spatial and mathematical subjects, demonstrating their interconnectedness [11,10]. A common definition of spatial intelligence is the ability to generate, recall, maintain, and manipulate visual-spatial images and solutions [12]. Spatial intelligence has played a crucial role in mathematics, as seen in the Theory of Relativity and the Periodic Table. This aligns with the perspective of the renowned mathematician Jacques Hadamard, who stated that mathematical discoveries first emerge as intuitions and visual-spatial representations, later subjected to validation through formal and symbolic logic.

According to Mix & Cheng [10], a consistent and strong correlation has been demonstrated between visual intelligence and broader mathematical problem-solving. For example, spatial intelligence has been linked to performance in geometry [13], numerical estimation [14], word problems (Hegarty & Kozhevnikov, 1999), and algebra [15] in their research, which has shown that spatial intelligence is associated with the algebraic abilities of students. Furthermore, the research also explained that spatial intelligence has a very strong relationship with scholastic aptitude. This indicates that spatial intelligence is not limited to its relevance in problem-solving in geometry but extends to other fields, as many branches of mathematics inherently possess spatial characteristics.

McGee [16] argues that mathematical ability is a combination of general intelligence, visual imagery, the ability to perceive numbers, spatial configuration observation, and the ability to store configurations as mental patterns. Spatial intelligence involves understanding left-right orientation, perspective understanding, geometric shapes, linking spatial concepts with numbers, and the ability to mentally transform visual images. These factors are also essential in learning mathematics. The role of spatial intelligence in mathematics is supported by several validity studies. McGee [16] examined the relationship between various spatial intelligence tests involving visualization and orientation, as proposed by Guilford and Zimmerman, and mathematics scores. It was found that there is a high correlation between spatial abilities and mathematics scores when compared to linguistic and reasoning tests. Similarly, a study conducted by McGuinness [17] discovered a connection between mathematical problem-solving and spatial intelligence. In investigating the role of spatial intelligence in high-level mathematical problem-solving, Smith (1980) concluded that there is a positive relationship between spatial intelligence and problem-solving involving advanced mathematical concepts, but it has less of a relationship with problem-solving related to low-level mathematical concepts such as arithmetic.

The use of spatial examples, such as creating diagrams, can help children master mathematical concepts. Teaching methods that incorporate spatial thinking, such as geometric shapes, spatially related toys (puzzles) that connect spatial concepts with numbers, and spatial tasks, can aid in problem-solving in mathematics [17]. Similarly, the understanding of concepts like division and proportions depends on prior spatial experiences [17].

School-aged children, in their cognitive development, are in the stage of concrete operational thinking. Children at this stage begin to exhibit logical-mathematical thinking. Piaget [17] explains this through the concept of conservation, where children are capable of understanding that something doesn't change in quantity or amount when its shape or arrangement is altered. Children realize that if the process is reversed, the form will return to its original state. Cognitive development and spatial representation are acquired by children through the perception and manipulation of objects, and not all aspects of geometric space are achieved simultaneously. Spatial-geometric development follows a specific sequence: topology, projective, and Euclidean. Based on this sequence, at the age of 7-8 years, children begin to develop spatial concepts distinct from the spatial perception or representation seen in children around the age of 2. Spatial representation is not merely a mirror image of what a child sees; it is a mental image, a representation of the environment resulting from activities in the environment. Over time, spatial representation begins to take shape, which Piaget referred to as spatial concepts. This can occur because by the time children reach the age of 7-8, they are no longer self-centered. They can recognize objects in terms of point pairs and can explore all aspects of those objects. With increasing age, the understanding of size, perspective, and proportion also grows, helping children understand that the world seen by others is the same as what they see. When this happens, space becomes an abstract concept, separable from experience. The following diagram provides examples of various types of actions that can typically be used to identify a student's spatial intelligence.

The studies above clearly stipulate that spatial intelligence has a positive influence on students' problem-solving abilities in various mathematical concepts. However, the most consistent and strong relationship is observed between spatial intelligence and mathematical problem-solving, especially in mathematical areas that can be visualized, such as geometry and algebra. Furthermore, some reasons why spatial intelligence can affect students' problem-solving abilities include: 1) individuals with good spatial intelligence have strong imaginative abilities, such as using diagrams in problem-solving and accurately depicting problem solutions; 2) they can correctly identify concepts related to the given problem and connect known data with existing concepts; 3) they find it easier to view problems from various perspectives, generate multiple ideas, multiple problem solutions, or multiple questions smoothly; and 4) they can quickly identify patterns in problem-solving.

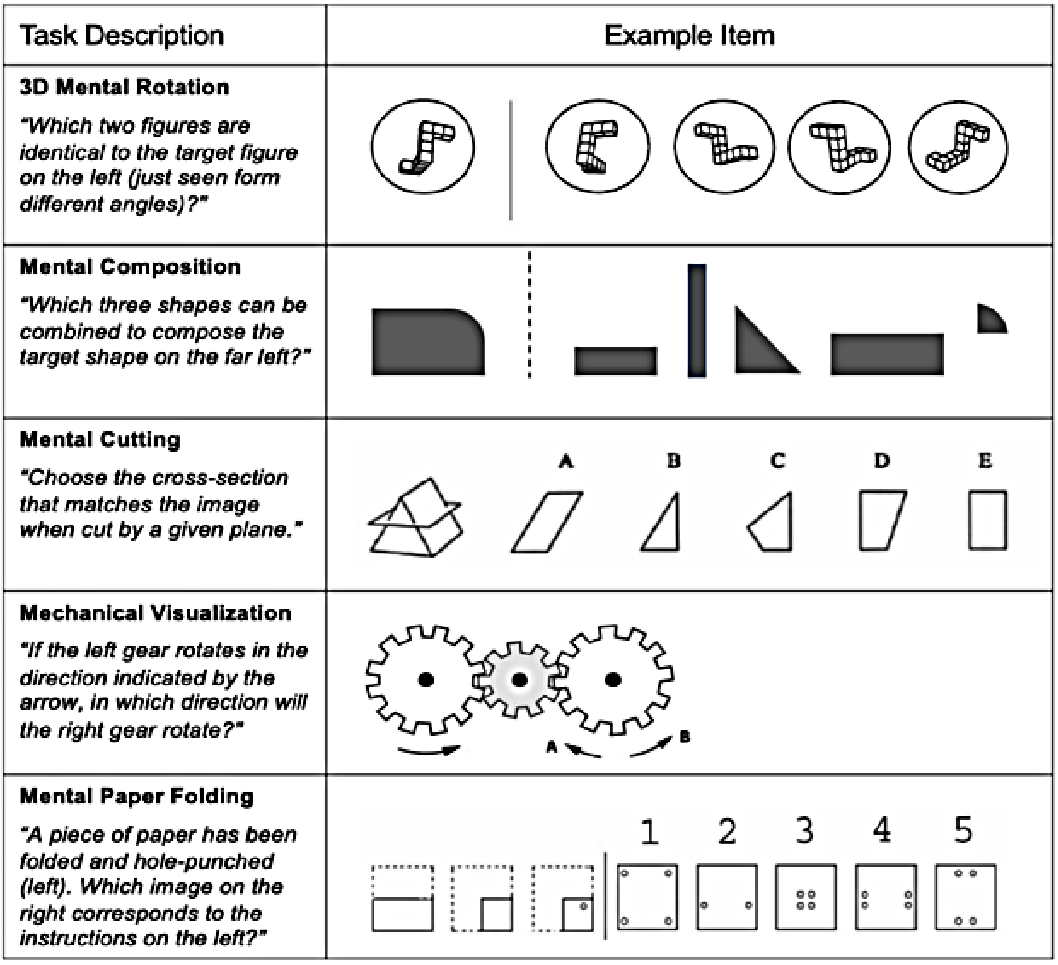

Fig. 1. Examples of measurements used to capture individual differences in spatial visualization skills

Furthermore, neurological case studies have shown that there is a relationship between spatial intelligence and mathematical problem-solving abilities because both rely on the same brain regions and neural computations. The emergence of medical technology tools such as MRI has paved the way for numerous researchers to conduct and deepen their studies on the relationship between spatial intelligence and mathematical abilities. Several neurological studies have indicated that in the intraparietal sulcus (IPS) region, numbers and space can interact [18]. The IPS and its surrounding areas play a crucial role in individuals thinking about various magnitudes, including non-symbolic representations, space (size and shape), lighting, and even abstract concepts like numbers and time [17, Walsh, 2003). Therefore, there is evidence suggesting that spatial processes and mathematical abilities rely on common areas within and around the IPS. Support for this is seen in Zacks' [19] meta-analysis results on mental rotation neural correlations. Zacks found evidence indicating that the IPS is the brain region most strongly and consistently associated with mental rotation. Other spatial processes, such as the ability to assemble/disassemble and translate geometric shapes, are also linked to activity in this region [20] (Seydell-Greenwald, Ferrara, Chambers, Newport, & Landau, 2017).

3.2 How can Linguistic Intelligence affect Problem-solving Abilities?

Mercer and Howe [21] reported that there is an increasing amount of evidence based on various research studies indicating that when conversations between teachers and students are of high quality and appropriate, they can serve as a powerful catalyst for the development of reasoning and improvement in academic performance. Linguistic intelligence is a person's ability to manipulate words effectively, both orally and in writing. Linguistic intelligence involves thinking about words, using language to express and appreciate complex meanings. According to Howard Gardner (2003), linguistic intelligence can be assessed based on several indicators, including: Rhetoric, which is the use of language to influence people to take specific actions. Mnemonics, which involves using language to remember information. Explanation, which involves using language to provide information. Metalanguage, which involves using language to understand language itself. As described by Gardner and his colleagues (Sinatra, 2012), individuals with linguistic intelligence typically exhibit the following characteristics: sensitivity to patterns, being organized and systematic, the ability to argue effectively, enjoyment of listening, reading, and writing, ease of working with words, a love for wordplay, a sharp memory for trivial details, and a talent for public speaking and debating.

The reciprocal relationship between linguistic intelligence and an individual's mathematical abilities has significantly increased over the past few decades, leading to a shift in the paradigm of education from teacher-centered to more student-centered learning. There is a greater emphasis on students' discursive skills in mathematics classrooms (Sally-Ann Robertson, 2020). Discursive skills are a part of linguistic intelligence and are defined as a form of logical, rational, and analytical thinking that utilizes language and reasoning. This type of thinking is most frequently performed by the conscious human mind. Some key characteristics of discursive thinking include: Step-by-step progression, occurring sequentially, such as steps in logical arguments. Symbolic, using symbols like words, numbers, and diagrams to represent concepts. Abstract, being more conceptual than experiential, involving abstract ideas and theories. Deliberate, requiring effort or concentration. Constrained, working within limits and boundaries to reach conclusions.

The relationship between linguistic intelligence and mathematical abilities has called for a more concrete focus on honing linguistic intelligence to assist students in solving mathematical problems and understanding the essentials required in problem-solving, such as explaining, reasoning, arguing, and defending mathematical thoughts. Despite the linguistic intelligence challenges associated with the complexity of language required to express mathematical thoughts, research that attempts to uncover mathematical problem-solving abilities without first providing access to develop students' linguistic intelligence has shown that most students struggle with mathematical thinking, thereby affecting their mathematical problem-solving abilities (Sally-Ann Robertson, 2020). Furthermore, Gervasoni [22] notes and ensures that all children who are expected to learn mathematics without concurrent development of linguistic intelligence will pose a threat to a child's mathematical development. When considering the needs required by students in mathematical problem-solving, it can be said that these needs intersect with linguistic intelligence. Mathematical problem-solving demands systematic, logical, critical thinking, and perseverance until a solution to a given problem is found [23,24]. In mathematical problem-solving, an individual needs skills to analyze, predict, reason, evaluate, and reflect [25,26]. Some of these skills, like predicting, reasoning, and reflecting, are part of linguistic intelligence, making their connection quite clear.

The relationship between linguistic intelligence and mathematical problem-solving ability can be explained simply as follows: linguistic intelligence can assist students, among other things, in mathematical communication. Developing mathematical communication skills is crucial in mathematics education because effective mathematical communication helps individuals solve mathematical problems. Therefore, linguistic intelligence plays a vital role in mathematical problem-solving. For instance, students can solve problems through mathematical modeling, which requires reasoning supported by linguistic intelligence. Similarly, when solving problems through mathematical thinking and modeling, linguistic intelligence is needed to understand and interpret the problem's intent. Mathematical communication tools such as symbols, tables, graphs, and diagrams are also essential in explaining solutions. Therefore, both strong linguistic intelligence and accurate mathematical modeling are necessary for problem-solving.

Mathematics is taught with the aim of preparing individuals to use mathematics and mathematical thinking in their daily lives. Mathematics education focuses on training and cultivating systematic, critical, creative, and consistent thinking. Understanding mathematics and solving mathematical problems, of course, requires strong linguistic intelligence support to make it easily comprehensible. The language of mathematics may seem challenging for beginners, so sufficient linguistic intelligence support is needed for the application of mathematical language. The use of precise language fundamentally characterizes mathematical proof. Although linguistic intelligence is related to mathematical problem-solving abilities, it cannot work alone but must be supported by other intelligences. As shown in a study by Windi FT (2022), linguistic intelligence is indeed essential in mathematical problem-solving, but it is not the sole factor needed. According to Carvin [27], intelligence is a multifaceted ability resulting from the development of cognitive science, developmental psychology, and neuroscience. These three fields of science conclude that a person's intelligence is actually a set of faculties that can work individually or "orchestrate" with others [27,28-32].

4. CONCLUSION

This study concludes that spatial intelligence is one of the essential intelligences in supporting students' mathematical problem-solving abilities. However, not all mathematical fields have a consistent and strong relationship with spatial intelligence. In the findings of this article, a strong and consistent relationship between spatial intelligence and mathematical problem-solving was observed in fields such as geometry and algebra. On the other hand, linguistic intelligence was found to have a reasonably consistent relationship with mathematical problem-solving. This can be attributed to the fact that mathematical problem-solving requires discursive skills, which are part of linguistic intelligence. Several studies have hypothesized a strong connection between spatial and linguistic intelligences in mathematical problem-solving. Still, further in-depth research is needed. It is crucial not only to state the existence of a relationship and its fundamental aspects but, more importantly, to explain how both intelligences are related to mathematical problem-solving, leading to a strong and consistent association. Therefore, further studies are required to delve deeper into the findings of this article, especially regarding the specific reasons and conditions that underlie such a significant association.

DISCLAIMER

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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