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Understanding Spatial Ability Development in Pre-Service Teachers: A Qualitative Study

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Abstract: This study investigated the spatial reasoning abilities of pre-service teacher candidates through a qualitative case study design. The research focused on identifying the strategies students used on the Mental Rotation Test (MRT) and exploring their conceptions of spatial reasoning. From a sample of 60 pre-service teachers, four participants representing a range of spatial abilities were purposively selected for semi-structured interviews. Findings reveal that students did not rely solely on holistic or analytic strategies but instead employed a combination of visualization, verbal reasoning, counting, and elimination techniques to solve spatial problems. High-ability students demonstrated a clear understanding of spatial reasoning, linking it to academic subjects such as geometry and visual arts, as well as to hobbies like puzzles and drawing. In contrast, low-ability students showed limited or inaccurate conceptions of spatial reasoning and faced difficulties mentally manipulating spatial objects. The study highlights gaps in spatial skills among teacher candidates and emphasizes the need for teacher education programs to explicitly support the development of spatial abilities and manipulation strategies.

Key words: pre-service teachers, spatial ability, mental rotation test, cognitive strategies

1. Introduction

Spatial reasoning is a crucial cognitive skill with wide-ranging applications in science, technology, engineering, and mathematics (STEM) (Mix & Cheng, 2012). In recognition of its importance, both the National Council of Teachers of Mathematics (2010) and the National Research Council (2006) have advocated for a more spatially-oriented approach to teaching and learning in K–12 curricula. However, spatial reasoning is not confined to a single academic domain but permeates multiple subjects and professional fields. Envisioning the shape or movement of an imagined object contributes to the understanding of intersections of solids in calculus, structures of molecules in chemistry, and the formation of landscapes in geology (Ishikawa & Newcombe, 2021).

Eisenberg and McGinty (1977) found that individuals with different levels of spatial ability often pursue distinct professional paths. More recent large-scale longitudinal research by Wai et al. (2009), involving a sample of 400,000 participants, reinforced this finding by demonstrating that spatial abilities assessed during grades 9–12 significantly predict entry into STEM careers over a decade later. In that study, individuals who entered STEM fields exhibited substantially higher spatial abilities than those in non-STEM domains. Notably, education majors—particularly those who later became preschool and primary school teachers—had the lowest spatial scores. This trend is concerning, given that early childhood educators play a crucial role in fostering foundational cognitive skills.

There has been an emerging focus on spatiality (spatial reasoning, spatial thinking or spatial sense) as a fundamental component of pre-school and primary years education (Brent, 2015). Children interact with their environment in three dimensions and begin developing spatial understanding long before formal schooling. This understanding is cultivated through visual stimuli, hands-on exploration, body movement, gesture use, and cognitive processes such as kinesthetic awareness and mental rotation. However, without intentional instructional support, spatial reasoning may remain underdeveloped. Research suggests that many elementary students face challenges in numeracy due to weak spatial representations of numerical concepts (Tahta, 1980). Therefore, it is imperative that teachers not only

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recognize the importance of spatial reasoning but also possess the confidence and pedagogical skills to support its development effectively in the classroom.

With this background, the present study focuses on prospective primary teachers. Understanding pre-service teachers' spatial reasoning abilities and their conceptions of spatial reasoning is especially important given the increasing emphasis on spatial skills within the primary school curriculum. The findings from this study are expected to provide valuable insights for researchers and educators in designing, developing, and evaluating effective spatial ability interventions for future teachers.

2. Theoretical framework

The development of spatial reasoning evolved alongside intelligence testing in the early 20th century. Thurstone (1938) examined key mental abilities. He developed and elaborated the 'space' factor. According to Thurstone (1950), there are three primary spatial factors enclosed in spatial ability. Literature published later proposed more descriptive terms (Smith, 1964) for the three primary factors proposed by Thurstone earlier.

- Mental Rotation (S1): Ability of differentiating orientation or angles.
- Spatial Visualization (S2): Ability of recognizing components of an object when they are displaced or moving away from an original position.
- Spatial Recognition (S3): Ability of using body orientation to relate to questions regarding spatial orientation.

Among these factors, mental rotation (image rotation) has been identified as a core capability (Patkin, 2018; Johnson & Bouchard, 2005). The seminal study by Shepard and Metzler (1971) is often considered a foundational work in spatial cognition (Cotabish et al.,2024). Mental rotation (MR) is commonly assessed using psychometric tests such as the Shepard and Metzler (1971), the Purdue Spatial Visualization Test for Rotations (Bodner & Guay, 1997), and the Mental Rotation Test (MRT) developed by Vandenberg and Kuse (1978). A substantial body of research has explored the cognitive strategies individuals use to solve MR tasks. Barratt (1953) was the first to differentiate between a "whole approach" and a "part approach." Later studies refined this distinction, identifying three primary MR strategies: spatial/holistic, verbal/analytic, and a combined approach (Linn & Petersen, 1985; Hsi, Linn, & Bell, 1997). The spatial/holistic strategy involves mentally manipulating an entire image and comparing it to a target. Individuals who use this method typically rely on visualizing and rotating the whole object in their minds. In contrast, the verbal/analytic strategy breaks the task into smaller components, using a systematic, step-by-step comparison of specific features. This approach requires minimal visual rotation and often involves verbal reasoning. The combined MR strategy integrates both holistic and analytic elements (Patkin, 2018).

Academic subjects play a pivotal role in fostering spatial reasoning. Disciplines such as geometry, geography, and chemistry inherently require students to visualize, mentally manipulate, and transform objects (Ben-Chaim, Lappan, & Houang, 1988; Clements et al., 1997; Ishikawa & Newcombe, 2021). Instruction in these areas often emphasizes visualization strategies, including mental rotation, spatial transformation, and deconstruction of shapes and structures. Beyond formal education, various informal activities have also been shown to support spatial skill development. Hands-on and visual-motor tasks such as model building, artistic pursuits (e.g., drawing, knitting, needlework), mechanical work (e.g., car repair), and digital engagement (e.g., playing video games) promote spatial thinking (Peterson et al., 2020; Novak & Tassell, 2015). Sports like soccer and basketball, as well as movement-based activities such as dance, further enhance spatial awareness by requiring individuals to navigate and respond to dynamic spatial environments (Pietsch & Jansen, 2012).

3. Rationale of the study and research questions

Currently, spatial ability is neither explicitly mentioned nor widely recognized in Myanmar school curriculum. For exploratory purposes, this study aims to investigate teacher candidates' spatial reasoning ability and their conceptions of spatial reasoning, providing foundational insights to inform future curriculum development and teacher education programs in Myanmar. Using spatial ability test and semi-structured interviews, the study addresses the following research questions:

RQ1. What strategies do students use when approaching spatial ability tests?

RQ2. What are students' conceptions of spatial reasoning and its importance?

RQ3. According to students, what hobbies, personal experiences, or academic subjects contribute to the development of spatial ability?

4. Methodology

4.1 Research Design

Due to the nature of the research questions, a qualitative approach was deemed appropriate for this study. A case study design was selected to enable an in-depth exploration of a particular group using multiple data sources (Creswell & Poth, 2018). One of the key considerations in designing a qualitative study is identifying the appropriate unit of analysis. As Patton (2002) emphasizes, determining the unit of analysis requires clarifying "what you want to be able to say something about at the end of the study" (p. 229). In this study, the unit of analysis is prospective teachers, as the focus is on understanding their spatial reasoning strategies, conceptions, and experiences.

4. 2. Participants

A total of 60 teacher candidates (27 male, 33 female) enrolled in a 4-year teacher training program at Yankin Education Degree College in Myanmar participated in the study. A purposive sampling technique was employed to select four participants representing a range of spatial ability levels and demographic backgrounds for the interview phase. This subset included two females and two males. For ethical reasons, pseudonyms were used throughout the study to protect participants' anonymity and maintain their privacy. Participants were coded as PF1 (Participant Female 1), PM2 (Participant Male 2), and so on. Patton (2002) recommends purposeful sampling strategy for maximum variation to capture a broad spectrum of experiences.

4. 3. Instrument

Spatial Reasoning Test.To classify participants into high and low spatial ability groups, a paper-based version of Vandenberg and Kuse's Mental Rotations Test (MRT) was administered. Originally, the 20-item MRT could be completed by students at various grade levels within about 10 minutes (Vandenberg & Kuse, 1978). For this study, the test was shortened to 15 items due to time constraints. The MRT demonstrated high internal consistency reliability with a Cronbach's alpha of .89 (n = 60). Each item presents a target figure alongside four alternatives, two of which are rotated versions of the target. Participants must identify the two correct rotated figures. Scoring awards 1 point for each correct selection, with a maximum possible score of 30 and a minimum of 0. Higher scores indicate greater spatial and mental rotation ability.

Semi-structured Interview. One-on-one interviews were conducted to explore students' cognitive processes and perceptions of spatial reasoning. The interview prompts were designed to gather qualitative data about participants' experiences with the Mental Rotation Test (MRT), the strategies they employed, their understanding of spatial reasoning, and the personal, academic, or extracurricular factors they believed contributed to their spatial abilities. Each interview lasted approximately 20 to 30 minutes.

4.4. Procedure

Official approval for the study was obtained from the Education College Principal prior to data collection. Participation was entirely voluntary, and only students who provided informed consent were included. MRT test was first administered to 60 participants in a controlled classroom setting. Participants completed a 15-item paper-and-pencil test within a 15-minute time limit. Instructions were read aloud to ensure clarity, and students were informed of the time constraints and scoring criteria. No external aids were permitted, and participants were instructed not to rotate the test paper. Interviews were conducted with a subset of participants, without disclosing their MRT results, and were audio-recorded with the participants' consent.

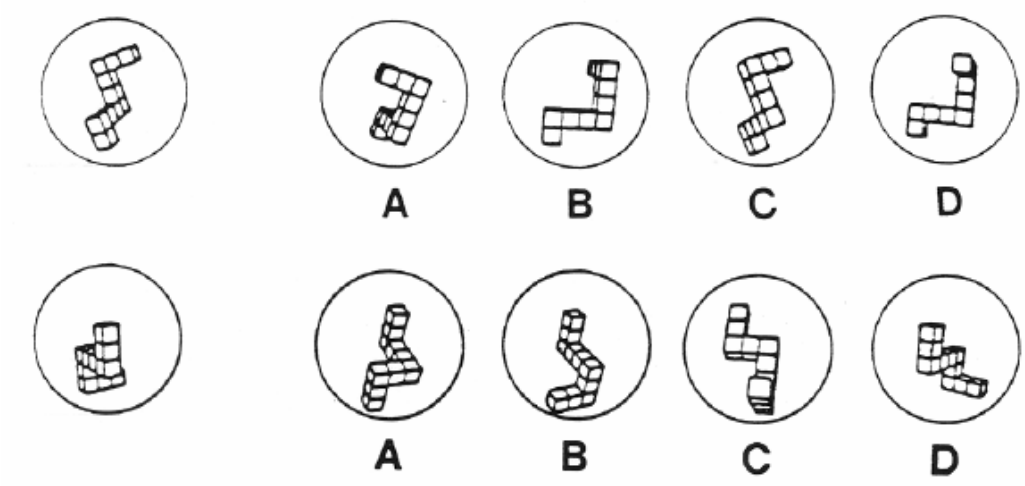

Figure 1. Two sample test items from the Vandenberg Mental Rotation Test (Vandenberg, 1978).

4.5. Data Analysis

Data from Mental Rotations Test (MRT) and semi-structured interviews were analyzed in a systematic manner. Scores from the Mental Rotations Test (MRT) were analyzed using descriptive statistics to determine the overall distribution of spatial ability among participants. The internal consistency of the MRT was calculated using Cronbach's alpha. Interview data were transcribed verbatim for a detailed analysis. A coding scheme was developed based on the research questions, using a combination of inductive and deductive coding methods (Linneberg & Korsgaard, 2019). Codes were organized into categories including 'test difficulty,' 'MRT strategies,' 'hobbies,' 'school subjects,' and 'conceptions and misconceptions about spatial reasoning'. To enhance the credibility of the findings, member checking was conducted with each participant. Narrative summaries were constructed for each interviewee, incorporating analytical insights and direct quotations to capture the depth and complexity of their experiences (Butina, 2015). Data from different sources (MRT test results, interview recordings, and narrative summaries) were triangulated to enhance the validity and reliability of the findings (Creswell & Miller, 2000).

5. Results

The MRT test was administered to all 60 students to determine the spatial ability of pre-service teachers. The range for students' scores was 7–30, with μ =18.33 and σ = 6.37. Students were classified as having high spatial ability if they were one standard deviation above the mean and low spatial ability if they were one standard deviation below the mean. Thirteen students were in the high spatial ability category while eleven were in the low category. The remaining were between one standard deviation below and above the mean (the mid-range spatial ability category) (Table 1).

Table 1. Spatial Ability level of pre-service teachers by gender and year level

Spatial Ability Level	First Year		Second Year		Third Year		Total
	male	female	male	female	male	female	
Low	0	1	5	1	1	3	11
Medium	3	8	4	4	9	8	36
High	1	5	0	0	4	3	13

The spatial ability levels of pre-service teachers varied by gender and year level. The majority of students fell within the medium level across all year-levels. In this study, male students were found more often in the low category, particularly in the second year, while females were more frequently represented in medium and high ability group in all year-levels. First-year and third-year students showed high spatial skill levels. To address the research questions, four participants were selected from different spatial ability groups and genders. The interview data were presented through narrative summaries, with a detailed student profile created for each participant.

Student Profile: PM1 (High Spatial Ability Group)

PM1 is a 21-year-old third-year teacher candidate who scored 26 out of 30 on the Mental Rotations Test (MRT), placing him in the high spatial ability group. About the MRTtest, he reported that he thought through the steps verbally in his mind (i.e., "two cubes up and three cubes down). He further mentioned that he chose the answers by excluding wrong alternatives. He noted his best strategy was counting, predicting and visualizing. These responses reflect a combination of holistic and analytical strategies, demonstrating flexibility in problem-solving approaches to spatial tasks. He reported the test was manageable and that the allotted time was sufficient. In the interview, PM1 described regularly engaging in spatially enriching leisure activities such as playing jigsaw puzzles, video games, and Tetris. PM1 believed that his hobbies helped him "see the hidden objects" and supported "picturing in the mind." He described, "Spatial reasoning is one of the skills all human's brain has according to Gardner's multiple intelligences" and further defined it as "the mental ability to estimate size, distance, and weight without direct measurement." PM1's responses demonstrated a clear understanding of spatial reasoning. He recognized its utility in academic contexts, particularly stating, "For example, in geometry, we need drawings from different perspectives. Seeing a cube or pyramid in two-dimensional net help us view the shape from another angle. Understanding this leads to a conceptual understanding of formulas for area and volume." When asked about the activities or subjects from the teacher training program that relate to spatial reasoning development, he connected spatial reasoning with hands-on science activities, such as creating teaching aids and constructing virtual 3D models in science, geography, and visual arts. Overall, PM1 demonstrated a well-rounded understanding of spatial reasoning, integrating theoretical knowledge, personal experience, and pedagogical insight. His responses suggest not only a strong grasp of spatial concepts but also a level of confidence in teaching them.

Student Profile: PF1 (High Spatial Ability Group)

PF1 was a 19-year-old first-year student who scored 24 out of 30 on the MRT, placing her in the high spatial ability group. She applied a mix of holistic and analytical strategies during the test. She revealed that she rotated the whole figure in her mind for most items when making comparisons. When she was stuck, she tried eliminating the answers that were clearly wrong and then focused on comparing the remaining options. She found that using her fingers to trace the shape in the air helped her see the rotation better. She reported that she always fixed her eyes on the target figure and compared all options to that one. However, she felt that time was not enough and had to guess some items. Her responses reflect a stronger reliance on a holistic visualization approach, where she intuitively rotated the entire shape in her mind rather than focusing on analyzing individual parts. Her hobbies include drawing and photography, both of which likely support her visual-spatial development. She mentioned that school subjects such as mathematics, geography, and visual arts contribute to developing spatial skills. Although she expressed awareness of the importance of spatial skills, she reported that she could not clearly describe the concept of spatial reasoning. However, she was able to explain its significance with a practical example: "The shapes of objects will be different….. like a pencil and a ruler. If the pencil is too flat, it will not be comfortable to hold in the hand and it will not be comfortable to write or draw. Therefore, the pencil is made long in the shape of a ball to write smoothly and conveniently." This example illustrates her intuitive understanding of how spatial properties—such as length, thickness, and form—impact an object's functionality. Overall, PF1 demonstrated an experiential and practical understanding of spatial reasoning, linking everyday object design to spatial thinking and providing real-world applications of geometric principles.

Student Profile: PF2 (Low Spatial Ability Group)

PF2 was a 21-year-old third-year student who scored 9 out of 30 on the MRT, placing her in the low spatial ability group. When asked about her test-taking strategies, she admitted: "I couldn't figure out the rotations, so I just looked for any small details that might be different. But mostly, I was guessing." Her response indicates difficulty with holistic visualization. Rather than mentally rotating the entire figure, she relied on identifying small, isolated features—such as a specific angle or corner—to guide her choices. This strategy reflects a limited analytical approach, often used by students who struggle to generate mental images of rotated objects. PF2 reported hobbies such as knitting, crocheting, and sewing. She noted that these activities help her calm her mind and concentrate, stating they are similar to the MRT in that both require focus. While these hobbies do involve some spatial processing—such as pattern recognition and fine-motor coordination—PF2 did not appear to explicitly connect them to spatial reasoning in a cognitive sense. She stated, "spatial reasoning is a kind of a self-control skill ….. it helps people think through problems and choose the best way to solve them". This response reveals a fundamental misunderstanding of the concept of spatial reasoning. While her answer emphasizes executive function and decision-making, it overlooks the essential definition of spatial reasoning as the ability to mentally manipulate, visualize, and understand spatial relationships among objects. When asked about academic experiences that support spatial skill development, she mentioned activities like poster-making, mind maps, and participation in math competitions. Although her explanation was not entirely aligned with the definition of spatial reasoning, her mention of visual and creative academic tasks suggests an implicit awareness of the role spatial thinking plays in organizing and interpreting visual information. These responses suggest that PF2 associates spatial ability with visual creativity, even if she lacks a precise conceptual understanding. Overall, PF2 demonstrated limited awareness of what spatial reasoning entails. Her strategies during the MRT, coupled with her vague and partially inaccurate definition of spatial reasoning, highlight that she has not yet developed a clear conception of this cognitive skill.

Student Profile: PM2 (Low Spatial Ability Group)

PM2 was a 20-year-old second-year teacher candidate who scored 9 out of 30 on the Mental Rotations Test (MRT), placing him in the low spatial ability group. During the MRT, he reported attempting a holistic strategy, stating: "I can get the right answer by taking a snapshot and analyzing it with my eyes." This indicates that he mentally rotated the entire figure as a single unit without breaking it down into individual parts. Although this approach can be efficient for some, it often lacks accuracy when the mental imagery is underdeveloped or when the cognitive load of the item exceeds working memory capacity. This was reflected in his performance, as he made numerous incorrect choices. He admitted struggling with the test, explaining: "For some of the questions, I just went with my gut. I couldn't really keep track of the rotations, so it felt like a guessing game." This highlights both the cognitive challenge he experienced and a lack of effective mental strategies for the test. PM2's primary hobby is playing football. While spatial awareness is often involved in sports—such as judging distances, predicting player movement, and understanding game positioning—he did not explicitly connect these experiences to cognitive spatial reasoning. When asked about his understanding of spatial reasoning, he described it as "thinking about things that are not practical," suggesting a perception that spatial tasks are abstract, disconnected from real-world utility. This response reflects a limited awareness of the broader relevance and application of spatial thinking. Such a perspective is consistent with many low spatial ability learners, who often view spatial reasoning as esoteric or overly theoretical. PM2 did not report any specific academic subjects or school activities that he believed contributed to the development of his spatial reasoning. This absence may reflect either a lack of emphasis on spatial thinking in the teacher training curriculum or limited student awareness of the spatial components embedded in subjects such as mathematics, science, and geography. Indeed, the current curriculum does not explicitly address spatial reasoning as a target skill. Overall, PM2 exhibited difficulty in mentally manipulating three-dimensional figures and held an abstract and somewhat disconnected view of spatial thinking. His inability to link spatial reasoning to academic content suggests that he has not yet formed a clear understanding of the concept. His experience highlights the broader challenges faced by students with low spatial ability—not only in task

performance, but also in recognizing the practical relevance and educational importance of spatial reasoning.

6. Discussion

This qualitative study aimed to explore the strategies used by teacher candidates when solving spatial tasks, their conceptions of spatial reasoning, and their perceptions of factors that contribute to the development of spatial ability. The data, drawn from interviews and test performance, reveal marked differences between students with high and low spatial abilities. The findings are discussed below according to the three research questions.

Participants demonstrated a range of cognitive strategies when tackling the Mental Rotations Test (MRT), with clear distinctions between high and low spatial ability groups. High-ability students (PM1 and PF1) reported using both holistic and analytical strategies. PM1, for example, described mentally narrating the steps involved in rotations, using elimination techniques, and focusing on structured mental processes like counting and predicting. PF1 used visualization extensively, reporting that she fixed her gaze on the target figure while tracing shapes with her fingers in the air. These findings suggest that high-performing students tend to blend visual-spatial manipulation with logical deduction, allowing them to engage deeply with spatial problems. In contrast, students with lower spatial ability (PF2 and PM2) expressed difficulty with the MRT. PF2 primarily relied on guessing and identifying small differences, admitting she “couldn’t figure out the rotations.” PM2 attempted holistic visualization by mentally spinning the whole shape, but described the process as a “guessing game” due to his inability to track the rotations. Their responses highlight the challenges faced by students who have not yet developed reliable spatial reasoning strategies, suggesting a need for physical manipulatives to support and scaffold their understanding

Participants’ conceptions of spatial reasoning varied significantly by ability level, with high-ability students showing a more accurate and integrated understanding of the concept. PM1 described spatial reasoning as “one of the skills all human brains have,” referencing Gardner’s theory of multiple intelligences. He understood spatial reasoning as the ability to mentally estimate size, distance, and volume, and emphasized its importance in daily life, school subjects, and effective teaching. Similarly, PF1, though unable to provide a formal definition, offered a functional description of spatial reasoning in terms of object design (e.g., the shape of a pencil). Both high-ability students linked spatial reasoning to practical, educational, and cognitive domains, recognizing its value for both learners and educators. By contrast, low-ability students showed unclear or partially incorrect conceptions. PF2 perceived spatial reasoning as a kind of “self-control” skill that helps focus and make decisions. While this reflects some recognition of cognitive effort, it misrepresents the spatial reasoning construct. PM2 viewed spatial thinking as overly abstract and not practically useful, which reflects both a conceptual gap and a sense of disconnection between spatial skills and real-world application. These findings suggest that students with low spatial ability may not only struggle with spatial tasks but also lack awareness of the role and relevance of spatial thinking in learning and life.

High-ability students identified multiple sources of spatial skill development. PM1 attributed his spatial abilities to engaging in activities such as puzzle games, video games, and visual tasks in science and mathematics. He described spatial reasoning as integral to interpreting visual aids, understanding geometry, and constructing 3D models in teacher training. PF1 connected her hobbies of drawing and photography to her ability to visualize and rotate figures, and she also mentioned mathematics, geography, and visual arts as subjects that support spatial skill development. In contrast, the low-ability participants provided less direct or informed responses. PF2 listed activities like knitting and sewing, which helped her focus, though she did not clearly explain how these relate to spatial reasoning. PM2 did not identify any school subjects that contributed to his spatial skill development and viewed spatial exercises as disconnected from practical learning. His response indicates a missed opportunity in the curriculum to make spatial reasoning explicit and meaningful to learners.

This study is limited by its small sample size, which may not fully capture the diversity of experiences and perspectives among teacher candidates. However, the in-depth qualitative approach provides rich, detailed insights into individual spatial reasoning strategies and conceptions. As such, future research

with larger and more diverse participant groups is recommended to validate and expand upon these findings, contributing to a more comprehensive understanding of spatial reasoning in teacher education.

Conclusion

Findings from this qualitative study provide valuable insights into spatial reasoning and highlight the need for closer alignment between teacher training curricula and the development of spatial skills. Disparities in teacher candidates' abilities and conceptions suggest that spatial thinking is often underemphasized in teacher education programs, indicating a need for targeted enhancements. Integrating hands-on learning activities, visual modeling, and digital tools can support the development of spatial reasoning—particularly for students who struggle with spatial tasks. Additionally, incorporating reflective discussions and explicitly linking spatial cognition to academic subjects and everyday experiences can deepen candidates' conceptual understanding. Strengthening spatial literacy within teacher preparation programs not only enhances future educators' cognitive abilities but also empowers them to foster spatial skills in their own classrooms, thereby enriching STEM education and better preparing students to meet the spatial demands of the real world.

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