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The relationship between spatial reasoning and geometric reasoning in teachers

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Abstract

This study assessed the spatial and geometric reasoning skills of primary school teachers and examined the relationship between these constructs. Participants were enrolled in a B.Ed. distance program at an education degree college in Myanmar. Results showed that male teachers outperformed females on the mental rotation test, though no significant gender differences were found in geometric reasoning. Younger teachers (aged 25-30) scored higher than older teachers (aged 46-55) in the geometric reasoning test. Teachers with mathematics and chemistry degrees performed better than those from other disciplines. Teachers struggled with tasks involving nets, three-dimensional (3D) shapes representation, rotations, and folding/unfolding solids. A moderate positive correlation (r = 0.47) was found between spatial and geometric reasoning. Matching edges and faces of 3D solids and measurement tasks were strong predictors of teachers' spatial reasoning. The findings imply that the teachers need to be sufficiently engaged in spatial reasoning activities.

Keywords: spatial reasoning, mental rotation skills, geometric reasoning, primary school teachers

INTRODUCTION

The National Council of Teachers of Mathematics (2010) and the National Research Council (2006) emphasized the need to integrate spatial reasoning into K-12 curricula. This has led to increased interest in developing students' spatial skills for success in STEM fields (Tian et al., 2022; Wai et al., 2009). A large-scale longitudinal study revealed that spatial skills assessed in high school students strongly predict entry into STEM careers 11 years later, with individuals employed in STEM fields demonstrating significantly higher spatial abilities than those in non-STEM professions (Wai et al., 2009). Notably, non-STEM education majors, including preschool and primary teachers, were found to have low spatial reasoning skills. This is particularly concerning, as teachers' spatial skills influence students' spatial learning at both the primary and secondary levels (Rocha et al., 2022).

Spatial skills are fundamental to understanding geometry. According to Lappan (1999), geometry education encompasses visualization, spatial reasoning, and representation, along with the analysis of two-dimensional (2D) and three-dimensional (3D) shapes and their transformations. However, Clements (2004) found that primary school geometry often focuses on superficial tasks, such as recognizing and naming shapes (e.g., squares, circles, and triangles) or categorizing them according to their properties (e.g., number of sides). While these tasks are important for building foundational knowledge, they do not engage students in higher-order thinking or spatial reasoning. Teachers should recognize the importance of spatial skills and provide students with the necessary experiences to develop spatial abilities, particularly in geometry learning from early childhood.

While spatial reasoning is critical in geometric thinking, its scope is much broader. Spatial reasoning involves seeing, inspecting, and reflecting on spatial objects, images, relationships and transformations (Battista, 2007). It encompasses a complex and interconnected set of processes, with various terms often used interchangeably, including "spatial ability," "spatial visualization," "spatial structuring," "visual

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Contribution to the literature

- The study investigated primary school teachers' performance on spatial and geometric reasoning tasks by employing the standardized mental rotation test (MRT) and mathematics curriculum-aligned geometric reasoning test for primary teachers.
- The study confirmed a significant relationship between spatial and geometric reasoning skills, while also examining how demographic factors such as age, gender, and academic background influence these abilities.
- The study underlines the need for targeted professional development to address gaps in teachers' spatial and geometric reasoning abilities.

thinking," "spatial sense," and "mental imagery". Examples of spatial reasoning include locating, orienting, decomposing/recomposing, balancing, diagramming, symmetry, navigating, comparing, scaling, and visualizing (Spatial Reasoning Study Group, 2015). Uttal et al. (2013) and van den Heuvel-Panhuizen et al. (2015) distinguished between two kinds of spatial skills: between-objects (extrinsic) and within-objects (intrinsic) skills. Each represents a distinct type of cognitive activity, with intrinsic skills, such as mentally rotating shapes, differing from extrinsic skills involving navigation.

As part of the recent curriculum reform, many topics are added to the new primary mathematics curriculum in Myanmar. Previously, mathematics textbooks had been unchanged for 30 years. There are four strands in primary mathematics curriculum of Myanmar: number, geometry, measurement, and mathematical relations. In the geometry strand, there are two sub-strands: plane geometry and solid geometry. In solid geometry, solid figures (3D shapes) are covered. In grade 1, students begin exploring shapes in their surroundings, such as boxes, cans, and balls. In grade 3, students are introduced to cubes, cuboids, and their nets as newly added topics (Ministry of Education, 2019). Students identify solid figures and learn to calculate the surface area and volume of solids in grade 6 through grade 9, including rectangular prisms, cylinders, pyramids, cones and spheres. Although the revised curriculum introduces many new topics, teachers need more practice and experience to digest those new items (Itoh et al., 2022).

Teachers who lack knowledge of spatial skills may continue to ignore spatial and geometric concepts and rely on rote memorization and procedural teaching. Despite the recognized importance of spatial skills in mathematics education, research on teachers' spatial reasoning and geometry abilities remains limited. This paper addresses such research needs with two specific objectives:

(1) to examine the spatial reasoning and geometry skills of primary school teachers in Myanmar to ensure effective mathematics instruction and

(2) to observe the connection between spatial and geometric reasoning among primary school teachers in Myanmar and offer recommendations for enhancing their spatial geometry instruction.

Building on the Pittalis and Christou (2010) framework, our study conceptualizes geometric reasoning as the ability to visualize, draw, construct, and effectively communicate about 2D and 3D shapes.

THEORETICAL FRAMEWORK

Spatial Reasoning: Concepts, Development, and Assessment

Spatial reasoning emerged as a distinct field of study with the introduction of intelligence testing in the early 20th century, although it was initially considered secondary to the general intelligence factor (G) (Lohman, 1993). Systematically exploring the cognitive processes underlying spatial reasoning gained momentum in the mid-20th century. Thurstone (1950) identified three spatial factors–S1, S2, and S3–within his seven primary mental abilities framework. S1, the first factor, pertained to recognizing objects from different angles. A classic example of this is orthographic projection in mechanical drawing, where individuals must understand and interpret the front, top, and side views of the same object. This skill is essential for tasks requiring the visualization of objects from multiple perspectives. S2, the second factor, involves the mental manipulation of internal parts of a configuration. This represents the ability to imagine the movement or displacement of components within a structure. S3, the third factor, encompasses spatial problems requiring awareness of the observer's body orientation. This factor is particularly relevant in tasks such as locating a point in a coordinate system or reading instruments, where the individual must account for their own position or perspective relative to the object or environment. Thurstone's (1950) work laid the foundation for the development of multiple measuring scales to assess discrete spatial abilities. Although the literature lacks consistency in the number of spatial factors, factor analytic studies have consistently identified two core components: spatial visualization and spatial orientation (Goldstein et al., 1990; McGee, 1979; Newcombe & Dubas, 1992). Spatial visualization involves mentally manipulating, rotating, or transforming visual stimuli, requiring recognition, retention, and recall of configurations with moving parts or 3D objects. In contrast, spatial orientation focuses on understanding how elements are arranged within a visual pattern and maintaining comprehension despite the changes in orientation (Gorska & Sorby, 2008).

Similarly, Linn and Petersen (1985) broadly defined spatial ability as the capacity to represent, transform, generate, and recall symbolic, nonlinguistic information. They identified three key spatial factors: spatial perception, mental rotation, and spatial visualization. Their meta-analysis highlighted several standardized instruments used to measure these skills. For spatial perception, common tests include the rod and frame test (RFT) and the water level task. For mental rotation, measures include the MRT by Shepard and Metzler (1971), the Vandenberg and Kuse (1978) test, PMA space (Thurstone & Thurstone, 1941), and flags and cards (French et al., 1963). For spatial visualization, widely used tests include the embedded figures test, hidden figures, paper folding, paper form board, surface development, and the differential aptitude test.

Mental rotation is widely recognized as one of the most extensively studied spatial ability in mathematics education literature (Harris, 2021). Shepard and Metzler (1971) conducted one of the pioneering studies of mental rotation. Building on Shepard and Metzler's (1971) experimental work, Vandenberg and Kuse (1978) created a standardized MRT for measuring individual differences in spatial reasoning. The MRT test involves one target image, two rotated identical images, and two mirror images, where subjects must determine if the rotated images are congruent with or mirror versions of the target. The task typically measures both speed and accuracy, though sometimes it is assessed under timed conditions. One key finding in mental rotation studies is that response time increases with greater angular deviation between the objects–participants take longer to identify congruent objects as the angle of rotation increases (e.g., 100-degree versus 40-degree rotations) (Károlyi, 2013).

The appropriateness of these tests depends on participants' age and cognitive development. For instance, the RFT and water level task are more suitable for children under the age of 13, while the MRT–which emphasizes speed and rapid mental manipulation–may not be ideal for young children due to their limited attention spans and developmental readiness. Despite the variety of spatial tests available, there remains a lack of access to reliable, valid, and well-normed instruments. Although hundreds of spatial ability tests exist, many are difficult to access or administer, and information about their psychometric properties is often limited (Uttal et al., 2024).

Spatial Reasoning and Gender Differences

The role of gender in spatial reasoning has been extensively studied, revealing a general trend of male advantage in certain spatial tasks. A large body of evidence suggests that women's spatial skills often lag behind their male counterparts. This has been linked to the underrepresentation of women in spatially demanding careers, such as engineering and architecture (Duffy et al., 2017). Pietsch and Jansen (2012) found gender differences in spatial cognitive performance, as measured by MRTs, with males outperforming females in sports and education, although not in music education. 3D mental rotation tasks reveal the greatest gender differences in spatial abilities and follows a developmental trajectory. The ability increases with age, but tends to decline in late adulthood (Károlyi, 2013). However, these findings on gender differences in spatial reasoning are inconsistent. Lowrie et al. (2016) report no gender differences in performance on the three constructs that measured students' spatial visualization, mental rotation, and spatial orientation. Similarly, Turğut and Yilmaz (2012) found no gender influence on Turkish preservice primary teachers' spatial orientation and spatial visualization skills.

One notable longitudinal study by Block and Block (1982), as cited in Linn and Petersen (1985), offers additional insight into the complexity of gender differences in spatial reasoning. They tested children using the embedded figures test at ages 3, 4, 5, and 11. Their results revealed a gender difference at age 4 that favored females, but no significant differences at other ages. This finding highlights the variability of gender effects across developmental stages, supporting the conclusion that spatial visualization is equally challenging for both sexes overall. While some studies highlight a male advantage in spatial reasoning, particularly in tasks such as mental rotation, the evidence is not universally consistent. Age, cultural context, and educational background may influence the presence or extent of gender differences. These mixed findings suggest that spatial reasoning abilities are not inherently gender-specific; instead, they are shaped by a combination of biological, environmental, and sociocultural influences.

Relationship Between Spatial Reasoning and Geometry

Historically, geometry has been deeply intertwined with spatial reasoning, with rich traditions developing over millennia. Examples include the geometric constructions found in ancient Vedic, Babylonian, and Greek altar designs, as well as the intricate arrangements of 2D tiles in the Islamic tessellations of the Alhambra. The work of Archimedes often considered the earliest "applied mathematician," also illustrates advanced spatial reasoning. Notable examples include his analysis of the Stomachion puzzle, his derivation of the area of a parabolic segment, and his method for calculating the volume of a hemisphere using what is now known as Cavalieri's principle (Davis, 2015).

The National Council of Teachers of Mathematics (2000) emphasizes the importance of geometrical reasoning across all educational levels. According to the National Council of Teachers of Mathematics' (2000) principles and standards for school mathematics, geometry instruction from kindergarten through grade 12 should support students in analyzing geometric shapes, formulating mathematical arguments, specifying locations and spatial relationships through coordinate geometry, applying transformations and symmetry, and using visualization and spatial reasoning to solve problems. In alignment with these goals, recent curriculum reforms have increasingly promoted transformational geometry, which encourages students to mentally manipulate 2D figures and 3D objects (Hawes et al., 2015a, 2015b). Building on this, Pittalis and Christou (2010) distinguished between spatial reasoning and geometric reasoning, noting that geometric reasoning encompasses the ability to carry out specific curricular tasks and apply relevant knowledge and skills. These include constructing nets, identifying and representing 3D objects in 2D, organizing cube arrays, and calculating the surface area and volume of solids.

Duval (1998) proposed that geometrical reasoning involves three interrelated cognitive processes: visualization, construction, and reasoning. Visualization refers to mentally representing geometric statements or exploring complex situations; construction involves identifying shape properties using tools like rulers, compasses, and folding techniques; and reasoning encompasses the discursive processes that support explanation, proof, and generalization (cited in Jones, 1998). Battista et al. (2017) further explored the link between spatial and numerical reasoning in the context of geometric measurement, introducing the concept of spatial-numerical linked structuring (SNLS). SNLS helps students understand how numerical operations are embedded in the spatial structure of objects. For instance, when asked to find the dimensions of a box with twice the volume of a 3 × 2 × 4 cm box, students often incorrectly double each dimension. SNLS reasoning supports more accurate strategies by highlighting the multiplicative relationships between volume and linear dimensions.

Empirical research strongly supports the link between spatial reasoning and mathematical achievement. Individuals who perform well on spatial tasks also tend to excel in mathematics, and this relationship is consistent across age groups and types of tasks (Lowrie et al., 2019; Newcombe, 2018; Uttal et al., 2013). Schenck and Nathan (2020) identified correlations between specific subcomponents of spatial reasoning and different mathematics skills in adults: mental rotation was linked to understanding change and relationships; spatial orientation correlated with quantity; and spatial visualization aligned with tasks involving space and shape. Similarly, Mix and Cheng (2012) found that visuospatial skills strongly predicted performance on number line estimation tasks, which rely heavily on proportional reasoning.

However, research shows that teachers' preparedness to teach spatial reasoning varies considerably. While many teachers integrate spatial reasoning into STEM instruction despite limited curricular guidance, others avoid spatial activities because of their own difficulties with spatial reasoning or anxiety about such tasks (Gilligan-Lee et al., 2022). Patkin and Barkai(2014) examined the geometric thinking levels (GTLs) of van Hiele among preservice and in-service teachers and found that their GTLs were higher for triangles and quadrilaterals than for circles and 3D figures. No participants demonstrated proficiency in the two highest levels for 3D geometric figures. Most had only internalized the first level of recognition or had not yet reached it, while the rest were classified as "inconsistent" in their mastery of GTLs.

Similarly, Moore-Russo et al. (2013) found that both preservice and in-service teachers exhibited underdeveloped spatial literacy, particularly in tasks involving 3D reasoning. Their performance was further hindered by limited spatial vocabulary and common misconceptions. Markovits et al. (2006) reported that teachers performed at levels comparable to third-grade students in visual estimation, free recall, and graphical reproduction, indicating low levels of visual cognition. Cohen (2008) also found inconsistencies in teachers' understanding of geometric concepts such as straight lines and planes, as well as confusion between formal definitions and mental imagery. These findings underscore the critical need to strengthen teachers' spatial reasoning skills–not only for their own professional competence but also to support the development of spatial thinking in their students. Enhancing spatial ability in teachers can lead to more effective geometry instruction and improved mathematical outcomes for learners.

METHODS

Research Question

Based on the significant literature indicating spatial reasoning is related to mathematics performance, the present study addresses the following research questions:

1. How do teachers perform on spatial reasoning and geometric reasoning tests?
2. Is there a difference in teachers' performance based on gender, bachelor's degree major, and age group?

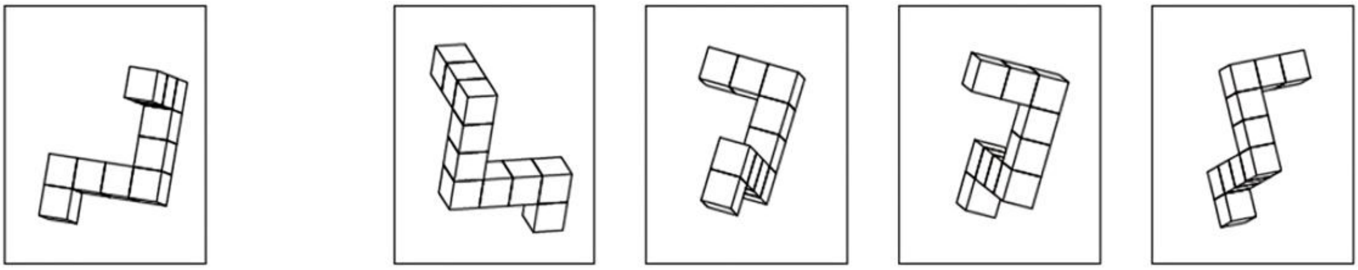

Figure 1. MRT (Peters et al., 1995).

3. How do teachers perform across the six tasks of geometric reasoning?
4. What is the relationship between spatial reasoning, geometric reasoning, and demographic factors?
5. How does the geometric reasoning test predict teachers' spatial reasoning ability?

Participants

The study included 161 primary school teachers (140 females, 21 males) enrolled in the B.Ed. distance program at Yankin Education Degree College, Yangon, during the 2023-2024 academic year. Participants hold bachelor's degrees in various disciplines as follows: Myanmar (27.3%), English (11.8%), mathematics (21.7%), chemistry (19.3%), and biology (19.9%). The ages of the participants ranged from 25 to 55 years, with the following distribution: 25-30 years (8.1%), 31-35 years (24.2%), 36-40 years (29.2%), 41-45 years (17.4%), and 46-55 years (21.1%).

Data Collection Instrument

Spatial reasoning test

Although there are various measures of spatial ability, not all tests are valid measures. Recent studies have found that Vandenberg and Kuse's (1978) MRT maintains its status as a robust measure of spatial ability with high reliability values (internal consistency reliability of around 0.88 and test-retest reliability of approximately 0.83) (Lochhead et al., 2022). A revised version of the MRT (Vandenberg & Kuse, 1978), as modified by Peters et al. (1995), was utilized in the present study with permission from Dr. Michael Peters. The MRT comprised 24 tasks, each presenting one standard drawing of a cube construction and four other drawings (**Figure 1**). Participants identified the two drawings, which were similar to the standard item. The tasks were given in two sets of 12, separated by a pause of 3 minutes. Teachers were allowed 3 minutes per set. Scoring was performed by awarding a point only if both correct choices for each task were identified. The paper-based version was administered, with a Cronbach's alpha reliability coefficient of 0.749.

Geometric reasoning test

Teachers' geometric reasoning ability was assessed using a 13-question instrument designed to evaluate their proficiency in manipulating both 2D and 3D geometric shapes. The test was adapted from the 3D geometry thinking test developed by Pittalis and Christou (2010). To ensure contextual relevance and to align the assessment tools with the intended research objectives, both national and international curriculum studies were systematically reviewed (e.g., Isoda et al., 2023; Ministry of Education, 2019). Specifically, Myanmar's primary education curriculum and textbooks–developed in collaboration with the Japan International Cooperation Agency–were examined to ensure the test content reflected newly introduced geometry topics at the primary level (Itoh et al., 2022). In addition, the SEAMEO curriculum textbook series by Isoda et al. (2023) was consulted to inform the selection and design of geometric problems, particularly those related to spatial and geometric reasoning, within the context of Southeast Asian educational frameworks. The test included various geometric reasoning tasks: construction of nets, manipulation of 3D shapes representation modes, structuring 3D arrays of cubes, matching edges and faces in folding/unfolding 3D solids, measurement, and visualizing rotations of 2D shapes and orientation in terms of cardinal directions after clockwise and anticlockwise rotations. To identify and reveal the teachers' geometric reasoning ability, short response questions were designed. Four preservice teachers, three specialists in mathematics education, and one measurement and assessment specialist were consulted to ensure that the questions were appropriate in terms of both content validity and face validity. The paper-based test was scored 1-0 according to the clarity and accuracy of responses. Administered in 40 minutes, it measured teachers' geometric reasoning, with a Cronbach's alpha reliability coefficient of 0.702.

Procedure

Official approval was obtained from the education college principal before the instrument was applied to the participants. Participation was entirely voluntary, and only those who willingly consented to take part were included in the study. The whole testing took place as a group test in the classroom setting. The MRT was

Table 1. MRT and geometry test mean scores and SDs by gender, age and major

Variables		N	MRT score		Geometry score	
			M	SD	M	SD
Gender	Male	21	3.71	3.69	4.86	3.34
	Female	140	1.84	2.12	4.11	2.39
Age	25-30	13	2.92	4.05	5.92	3.45
	31-35	39	2.33	2.65	4.56	2.64
	36-40	47	2.26	2.45	4.55	2.38
	41-45	28	1.82	1.83	3.71	2.46
	46-55	34	1.44	1.76	3.09	1.69
Major	Myanmar	44	2.20	2.37	2.95	1.99
	English	19	1.84	1.57	2.79	1.62
	Mathematics	35	3.20	3.75	5.71	2.99
	Chemistry	31	1.65	1.28	5.26	2.53
	Biology	32	1.25	1.57	4.13	1.72
General		161	2.08	2.45	4.21	2.53

Table 2. Results of Mann-Whitney U test on teachers' MRT scores

Gender	N	Mean rank	Sum of ranks	U	*p*
Male	21	103.71	2,178.00	993	.014
Female	140	77.59	10,863.00		

administered first, followed by the geometric reasoning test, and finally, questions about gender, age, and university majors were asked. All participants' answers were analyzed and scored by both authors.

Data Analysis

Teachers' performance on the spatial reasoning (MRT) and geometric reasoning tests were summarized by descriptive statistics, including mean, standard deviation, and frequency distributions. Percentages of correct responses for individual test items were calculated, identifying areas of strength and weakness in the geometric reasoning test. The relationships between variables were examined with Spearman's correlation, conducted to assess the association between MRT and geometric reasoning scores. Multiple regression analysis was performed to explore the predictive power of geometric reasoning on spatial reasoning. All statistical analyses were performed using the SPSS 25.0 software program.

RESULTS

Teachers' Performance on Spatial Reasoning and Geometric Reasoning Tests

Descriptive statistics were used to examine teachers' spatial reasoning and geometry reasoning levels. The spatial reasoning test (MRT) and geometry reasoning test scores were compared across gender, age groups, and academic majors (see **Table 1**). For the MRT, the highest mean score was observed in the 25-30 age group (mean [*M*] = 2.92, standard deviation [*SD*] = 4.05), while the lowest mean score was observed in the 46-55 age group (*M* = 1.44, *SD* = 1.76). Male teachers outperformed female teachers (*M* = 3.71, *SD* = 3.69 vs. *M* = 1.84, *SD* = 2.12), and mathematics majors had the highest mean MRT score (*M* = 3.20, *SD* = 3.75), while biology majors had the lowest (*M* = 1.25, *SD* = 1.57). Overall, teachers' performance on the MRT was relatively low, with a mean score of *M* = 2.08 (*SD* = 2.45).

Similarly, for the geometry reasoning test, the highest mean score was observed in the 25-30 age group (*M* = 5.92, *SD* = 3.45), while the lowest mean score was observed in the 46-55 age group (*M* = 3.09, *SD* = 1.69). Male teachers outperformed female teachers (*M* = 4.86, *SD* = 3.34 vs. *M* = 4.11, *SD* = 2.39), and mathematics majors had the highest mean score (*M* = 5.71, *SD* = 2.99), while English majors had the lowest (*M* = 2.79, *SD* = 1.62). Overall, teachers performed relatively poorly on the geometric reasoning test, with a mean score of *M* = 4.21 (*SD* = 2.53).

Differences in Teachers' Performance by Gender, Bachelor's Degree Major, and Age

The Mann-Whitney U test (**Table 2**) showed a statistically significant difference in teachers' MRT scores, $U = 993$, $p < .05$, $r = .19$. The results indicate that male teachers performed better than female teachers on the MRT. However, there was no significant difference in teachers' geometry scores by gender, $U = 1342$, $p = .52$, $r = .05$.

Further, MRT and geometry scores were categorized into low (≤ median) and high (> median) groups, with median scores of one for MRT and four for geometry (**Figure 2**). A higher proportion of female teachers were in the low-MRT (52.1%) and low-geometry groups (62%) than male teachers (38.1% for MRT, 52% for geometry). This suggests that female teachers were likelier to score below the median in both tests.

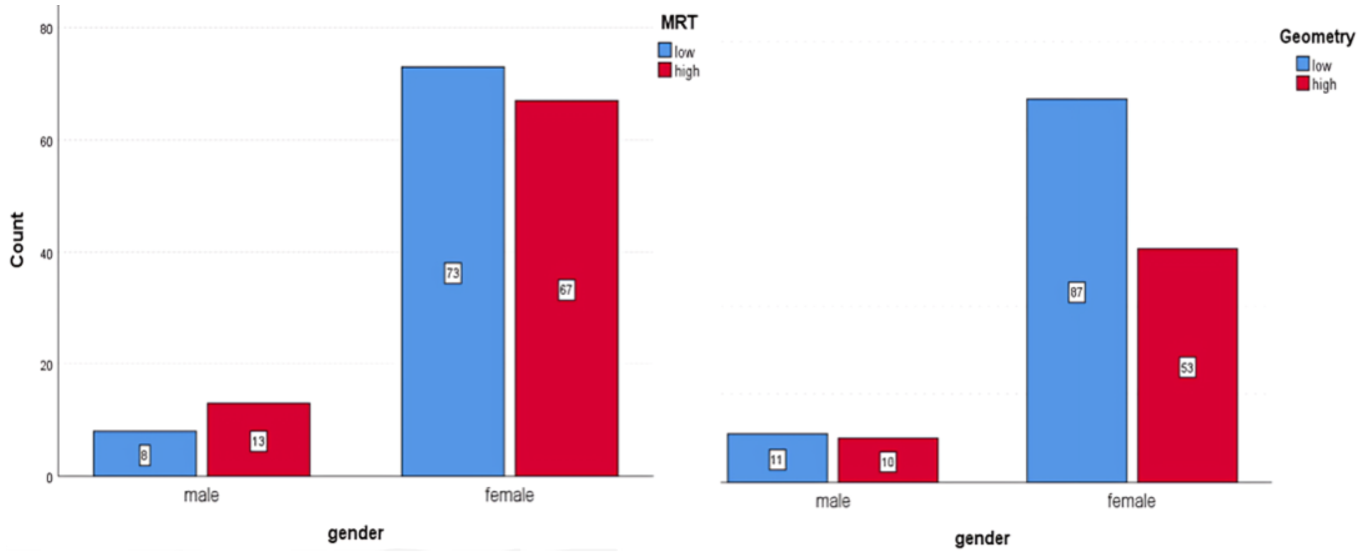

Figure 2. Distribution of male and female teachers showing different performance levels (Source: Authors' own elaboration)

Table 3. Achievement percentage of geometric reasoning tasks

No	Geometric reasoning tasks	N	Score	Correct percentages (%)
1	Construction of nets (1 item)	161	18	11.20
2	Manipulation of 3D shapes representation modes (2 items)	161	77	23.91
3	Structuring 3D arrays of cubes (1 item)	161	102	63.40
4	Matching edges and faces in folding/unfolding 3D solids (3 items)	161	137	28.36
5	Measurement (3 items)	161	222	45.96
6	Visualizing rotations of 2D shapes and Orientation (3 items)	161	122	25.26
Total		161	678	32.40

Teachers' score differences were also analyzed by academic major and age group. A Kruskal-Wallis test indicated no statistically significant difference in teachers' MRT scores across different majors, $H(4) = 6.715$, $p = .152$ and across different age groups, $H(4) = 3.664$, $p = .453$. However, there was a statistically significant difference in teachers' geometry scores across different majors, $H(4) = 33.41$, $p < .001$, $\eta^2 = .19$ and age groups, $H(4) = 13.45$, $p < .01$, $\eta^2 = .06$. Post-hoc pairwise comparisons revealed that teachers with Myanmar majors scored significantly lower than both chemistry ($z = -4.169$, $p < .001$, $r = .48$) and mathematics groups ($z = -4.582$, $p < .001$, $r = .52$). Similarly, English teachers scored significantly lower than both chemistry ($z = -3.415$, $p = .006$, $r = .48$) and mathematics teachers ($z = -3.703$, $p = .002$, $r = .50$). These results indicate that mathematics and chemistry teachers outperformed Myanmar and English major teachers in geometry reasoning test. Moreover, young teachers aged 25-30 scored significantly higher than older teachers aged 46-55 on the geometry reasoning test, $z = 2.898$, $p = .038$, $r = .42$.

Teachers' Performance Across Six Geometric Reasoning Tasks

The geometric reasoning ability of teachers was assessed using a 13-question test, including various geometric reasoning tasks. All tasks were scored as one for correct and complete demonstrations of understanding and zero for incorrect or incomplete answers. Detailed task descriptions, along with examples, are presented in **Appendix A**. A frequency table was prepared to analyze teachers' performance across the six types of geometric reasoning tasks. **Table 3** summarizes the participants' scores and percentage of correct responses for each task.

Participants performed differently across the various geometric reasoning tasks. The results indicate that teachers demonstrated a basic level of competency in geometry with a median score of one in measurement, structuring 3D cubes, and orientation items. However, teachers' performance was notably lower in 3D manipulation, receiving a median score of zero in tasks involving constructing nets, 3D shape representation, and matching edges and faces in 3D solids.

Table 3 shows the lowest percentage of correct responses (11.2%) was found in drawing a cube net that differed from the given examples in the question. Most teachers gave their answer by drawing a solid cube, indicating a lack of familiarity with cube nets. Some teachers drew incomplete nets with fewer than six squares, while others produced drawings that did not form a proper cube (**Figure 3**). Some teachers simply copied the provided nets or made superficial changes,

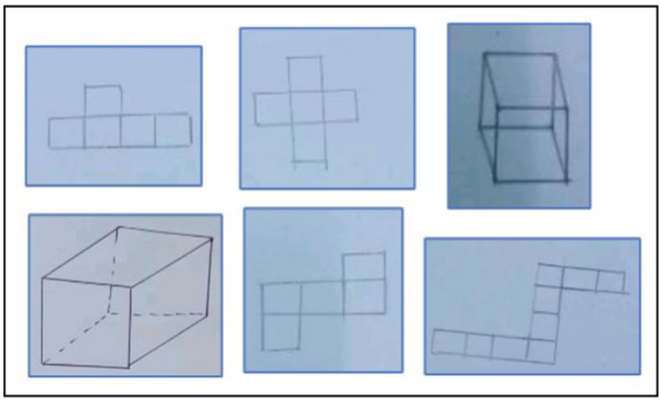

Figure 3. Task-1: Teachers' drawings of cube nets (Source: Authors' own elaboration)

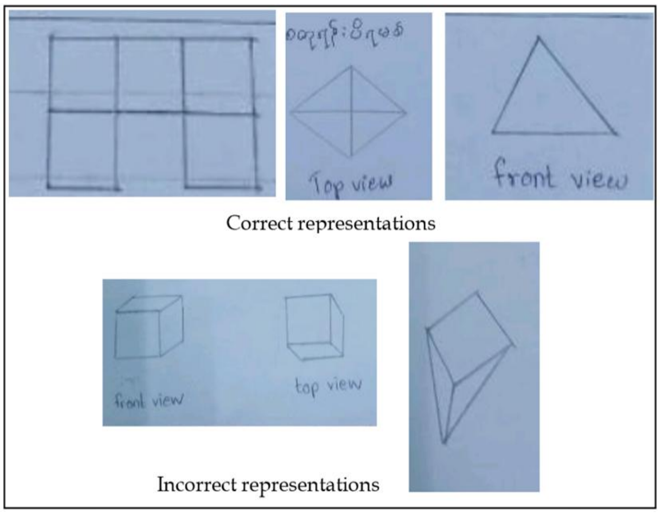

Figure 4. Task-2: Teachers' representations of 3D shapes (Source: Authors' own elaboration)

such as reflecting the figures left to right or altering their top-down orientation. However, they were expected to generate structurally different nets.

The correct response rate for tasks involving 3D shape representation was low, at just 23.91%. In the first task, many teachers struggled to accurately draw the top view of a two-layer structure. In the second, instead of providing the required orthographic projections of a square-based pyramid, many drew the full 3D object or gave irrelevant responses. These errors indicate a misunderstanding of the distinction between 3D shapes and their 2D projections (**Figure 4**).

Visualizing the rotations of 2D shapes and their orientations proved to be another challenging aspect of the geometric reasoning test, with a correct response rate of only 25.26%. While most teachers performed well on the orientation task, correctly identifying directions after anticlockwise rotations, they struggled with visualizing the rotation of 2D shapes. Many were unable to determine the correct 3D solid formed when rectangular and triangular shapes were rotated in space. Instead, most teachers incorrectly identified the resulting shapes as cuboids, pyramids and right triangles.

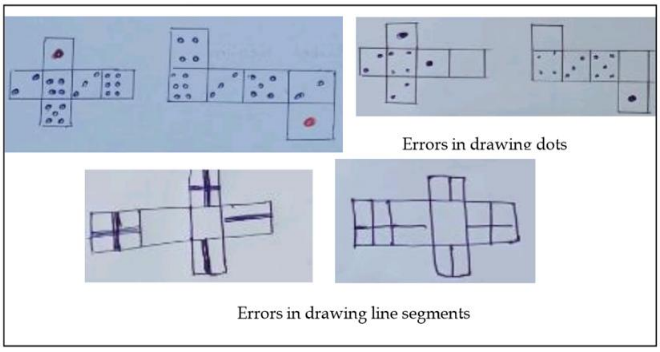

Figure 5. Task-4: Teachers' drawings of folding/unfolding 3D solids (Source: Authors' own elaboration)

Folding and unfolding 3D solids was one of the most challenging tasks in the geometric reasoning test, with only 28.36% of responses being correct. Teachers performed better on simpler tasks, such as drawing dots on a die where opposite faces sum to seven and drawing line segments on surfaces to represent a ribbon wrapped around a box. However, some teachers still made mistakes due to difficulties with spatial visualization (**Figure 5**). More teachers struggled significantly with complex tasks, particularly in determining how edges connect when folding a solid that is not cubic in shape. Strong spatial visualization skills are required to perform the tasks of predicting how faces, edges, and vertices will align after folding.

Measurement and enumeration of cubes were relatively easier than other tasks, with correct response rates of 45.96% and 63.40%, respectively. However, teachers still commit errors, such as adding lengths for surface area and double counting the overlap, miscounting cubes in arrays, and incorrectly applying formulas (e.g., failing to subtract truncated sections or misinterpreting dimensions). These mistakes highlight ongoing challenges in accurately applying geometric concepts and visualizing spatial arrangements, despite the tasks being less complex than others. The overall achievement percentage in the geometric reasoning test was 32.40%, indicating that teachers, on average, answered approximately one-third of the questions correctly. This relatively low performance suggests weak spatial reasoning and difficulty in accurately applying geometric knowledge. Teachers need regular practice in visualizing spatial relationships to improve their ability to complete tasks accurately and enhance their overall spatial reasoning abilities.

Relationship Between Teachers' Spatial Reasoning, Geometric Reasoning Skills, and Demographic Factors

Spearman's rank-order correlations were run to examine the relationships between spatial reasoning, geometric reasoning, and demographic factors. The results revealed a statistically significant positive correlation between spatial reasoning and geometric

Table 4. Correlations among constructs

Construct	1	2	3	4	5
Gender	1	.161*	.044	-.194*	-.051
Age		1	.058	-.129	-.266**
Major			1	-.128	.306**
Mental rotation score				1	.465**
Geometry reasoning score					1

Note. Variables of significance (*$p \leq .05$ & **$p \leq .01$)

reasoning test scores, $r = .47$, $p < 0.001$, indicating teachers with higher spatial reasoning abilities tend to perform better on the geometric reasoning test. A significant negative correlation was found between gender and MRT scores ($r = -.19$, $p < .05$), with female participants scoring lower on the MRT. A significant negative correlation was also found between older participants and geometric reasoning test scores ($r = -.27$, $p < .001$), while participants who were science majors (mathematics and chemistry) showed a positive correlation with geometric reasoning test scores ($r = .31$, $p < .001$) (**Table 4**).

Regression Analysis of Geometric Reasoning as Predictors of Spatial Reasoning

First, simple linear regression was used to assess whether geometric reasoning scores significantly predicts performance in spatial reasoning tests. The results of the regression suggested that geometric reasoning test scores explained 29% of the variance, $R^2 = .29$, $F(1, 159) = 65.83$, $p < .001$. Geometric reasoning test scores significantly predicted teachers' performance on MRT test, $\beta = .52$, $t = 8.11$, $p < .001$. Next, multiple regression analysis was performed to examine which specific geometric reasoning tasks best predict spatial reasoning test scores. Six geometric reasoning tasks were included in the analysis. Analysis of collinearity diagnostics showed no significant multicollinearity among the independent variables, with all VIF values below 5 and tolerance values above 0.2. The plot of standardized residuals vs standardized predicted values showed no obvious signs of funneling, suggesting the assumption of homoscedasticity has been met. The Durbin-Watson statistic (1.65) showed the values of the residuals are independent, as the obtained value was close to 2 and no influential outliers were detected (Cook's distance < 1).

The regression model using spatial reasoning test scores as the dependent variable (**Table 5**) presents the percentage of variance explained by each independent variable. The results reveal that the independent variables account for 34.8% of the variance ($R^2 = .35$, $p < .001$). Among the geometry reasoning tasks, matching edges and faces and measurement tasks were significant predictors of spatial reasoning performance. Calculating the surface area and volume of solids, and matching edges and faces while mental folding of 3D shapes, requires strong cognitive abilities and visualization processes, which are critical for accurately solving these geometry problems, as noted by Duval (1998). Specifically, measurement task, $t = 4.22$, $p < .001$, and matching task, $t = 3.99$, $p < .001$ were the geometric reasoning test items that significantly predicted spatial reasoning ability.

Table 5. Results of multiple regression analysis for MRT score as dependent variable

Independent variables	r	β	$r \cdot \beta \cdot 100$	p
Construction of nets	0.257	0.135	29.66	0.064
3D shapes representation	0.078	-0.082	-0.64038	0.256
3D arrays of cubes	0.257	0.029	0.73977	0.693
Matching edges and faces	0.455	0.321	14.62333	< .001
Measurement	0.435	0.310	13.47104	< .001
Orientation	0.323	0.082	2.661929	0.287
Total variance explained			34.83	

Note. N = 161; F (160) = 13.72; & $p < .001$

DISCUSSION

The findings of this study were analyzed in relation to the study's research questions. The primary aim was to assess teachers' overall performance in spatial reasoning and geometric reasoning tests. The study also investigated the relationship between spatial reasoning and geometric reasoning skills. Finally, the analysis also examined which geometric reasoning tasks best predict spatial reasoning performance. Our study relied on a single instrument for measuring spatial skills due to time constraints and concerns over excessive participant burden. Nonetheless, the MRT is a key assessment tool in cognitive psychology and mathematics education (Shepard & Metzler, 1971). As emphasized by Bruce and Hawes (2015), mental rotation is a fundamental spatial skill, and the MRT, a standardized assessment tool, allows for meaningful comparisons across studies.

The results indicate that primary school teachers' spatial reasoning skills were significantly weak. Specifically, Myanmar primary school teachers–regardless of age, gender, or academic specialization–demonstrated notably low performance on the standardized MRT. This finding aligns with previous studies. Wai et al. (2009) reported similarly low spatial reasoning abilities among teachers, while Yurt and Tünkler (2016) found that teachers generally exhibited limited spatial skills, with male teachers outperforming females, particularly among those with a background in social sciences. Likewise, Atit et al. (2018) observed that primary school teachers tend to possess weaker spatial abilities compared to their secondary STEM counterparts. The concerning spatial skill levels observed in this study have important pedagogical implications, as spatial reasoning has been shown to correlate with both content knowledge and pedagogical content knowledge (PCK) (Otumfuor & Carr, 2017). These findings underscore the urgent need for targeted professional development initiatives aimed at strengthening spatial reasoning abilities among primary school teachers.

While much research has been conducted on PCK, less attention has been paid to teachers' mathematical content knowledge. This study focused on geometry to explore the interaction between spatial skills and domain-specific knowledge. The results revealed that teachers performed poorly in the geometry reasoning test. This test was adapted from Pittalis and Christou's (2010) instrument, originally developed to assess students' 3D geometric thinking in grade 5 through grade 9. Analyzing teachers' performance across six types of geometric reasoning tasks demonstrated various competency levels. The most challenging tasks were recognizing and constructing nets, manipulating 3D shape representations, and visualizing 2D shape rotations. This finding is particularly concerning in light of recent curricular changes that introduce solid geometry into the primary mathematics curriculum. The urgent need for teachers to develop spatial skills aligned with curriculum demands is evident.

Regarding individual differences, gender disparities were observed in spatial reasoning scores, with male teachers significantly outperforming their female counterparts on the MRT. This finding is consistent with Shepard and Metzler's (1971) foundational work and a substantial body of subsequent research that has consistently reported gender-based differences in spatial reasoning performance (Duffy et al., 2017; Tsui et al., 2014). According to Baron-Cohen et al. (2003), these differences may be attributed to distinct cognitive and psychological factors identified in their work on the empathy-systemizing quotient. Specifically, males tend to exhibit stronger systemizing tendencies, while females generally score higher on measures of empathy. Systemizing is considered a powerful cognitive mechanism for understanding and predicting the law-governed, inanimate universe, whereas empathizing facilitates the understanding and prediction of social behavior. However, no significant gender differences were found in geometry reasoning test scores, suggesting that male and female teachers struggled with geometric reasoning tasks. Additional demographic factors, such as age and academic major, influenced teachers' performance on the geometry reasoning test. Mathematics and chemistry majors outperformed their peers majoring in disciplines, indicating that domain-specific training influences geometric reasoning proficiency. However, no significant differences in MRT performance were found among teachers with different academic majors or age groups.

Age-based comparisons found that younger teachers (aged 30-35) performed significantly better in the geometry reasoning test than older teachers (aged 45-55). This finding suggests that mathematical content knowledge does not necessarily improve with teaching experience alone. Researchers agree that while PCK develops through professional experience, teachers' specialized content knowledge–such as geometric reasoning–remains largely unchanged over time (Lowrie & Jorgensen, 2015). Consequently, older teachers with extensive teaching experience still performed below their younger counterparts on the geometric reasoning test. To address this gap, it is essential for these teachers to update their curricular knowledge. Spatial abilities develop with practice, and teachers should be provided with workshops or training focusing on enhancing spatial reasoning skills through activities such as paper folding, manipulatives, and hands-on tasks. Additionally, incorporating collaborative workshops or peer-learning groups could enrich the learning experience, allowing teachers to share insights and practical strategies for improving spatial reasoning instruction in the classroom.

Consistent with the previous studies, there was a moderately strong correlation and a predictive link between teachers' spatial reasoning and mathematical performance (Uttal et al., 2013; Wai et al., 2009). The regression model accounted for 35% of the variance in spatial reasoning test (at an alpha level of $p < .001$), indicating geometric reasoning tasks included in the study contributed significantly to spatial reasoning performance. Pittalis and Christou (2010) found the highest regression coefficient of spatial abilities on students' measurement reasoning. Conforming with this, the study revealed that mental folding of 3D solids and measurement are statistically significant predictors of spatial reasoning among the geometric reasoning tasks. This is likely due to their close relationship with cognitive processes such as visualization and SNLS reasoning. Mental folding of 3D solids involves creating, rotating, and manipulating objects in space, while measurement concepts in solid geometry require understanding spatial relationships between dimensions rather than relying on procedural calculations. Together, these tasks highlight the critical role of spatial skills in geometric reasoning.

In the present model, a large portion of variance is left unexplained. In the field of cognitive psychology, studies of mental rotation have provided unparalleled insight into the nature of mental representation and spatial imaging (Shepard & Metzler, 1971). During a mental rotation, the respondent's internal cognitive processes have a one-to-one correspondence with the external rotation of the object and relies on the cognitive ability to imagine the movement or displacement of components within a structure (Linn & Petersen, 1985). Unlike this, as Fujita et al. (2020) pointed out, geometric reasoning relies heavily on domain-specific knowledge. Successful problem-solving in geometry often requires the correct application of geometric principles and properties, as well as effective encoding and decoding of visual information and mental manipulation of shapes. Nonetheless, the model underscores the significant interplay between spatial abilities and mathematical proficiency, particularly in the domain of geometry.

Teachers in this study exhibited limited exposure to spatial tasks and rich geometry learning experiences. Addressing this gap requires structured, hands-on professional development that incorporates spatial representations and geometric tools, including diagrams, 3D models, and drawings. Dynamic geometry software (e.g., GeoGebra) can further support spatial reasoning by enabling interactive exploration of geometric concepts. Given teachers' central role in student learning, these findings highlight the need for targeted interventions to enhance teachers' spatial and geometric reasoning in alignment with curricular demands.

CONCLUSION

Investigating spatial reasoning among primary school teachers ensures they are well-prepared to teach spatially demanding geometry topics and effectively support student learning. This study focused on teachers' spatial skills and abilities to visualize, manipulate, and reason about geometric shapes. While extensive research on the relationship between students' spatial and mathematical abilities has been conducted, studies on teachers' competencies in this area are scarce, often due to the perceived sensitivity of evaluating educators. This study confirmed the relationship between spatial and geometric reasoning, highlighting that many teachers lack essential skills in these areas. However, the use of a convenience sampling method limits the generalizability of the findings. Additionally, the geometric reasoning test included a relatively small number of items in each category. Incorporating multiple spatial reasoning assessments–such as paper folding tasks and general reasoning tests like the Raven progressive matrices–could offer deeper insights into teachers' cognitive abilities. Future research should expand the participant pool to include a wider range of teachers, such as middle and high school teachers, to provide a more comprehensive understanding of teachers' spatial and geometric reasoning skills.

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Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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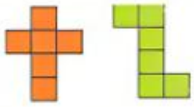
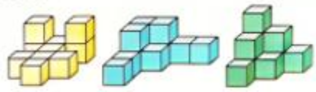
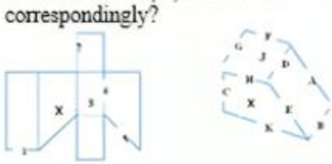
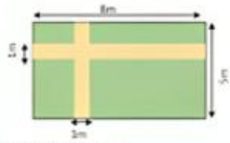
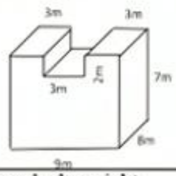
APPENDIX A: GEOMETRIC REASONING TEST

Ability	Description of Tasks	Example
Construction of nets (1 item)	1.Construction of a cube net	Draw a different cube net that is not like the two shown. 
Manipulation of 3D shapes representation modes (2 items)	2. Translation of a side projection view to an orthogonal one 3. Recognition of 2D views (a front and top view) of square based pyramid	Draw a top down 2D view of the given figure. 
Structuring 3D arrays of cubes (1 item)	4.Enumeration of the cubes shown in layers	How many unit-sized cubes are there in total? 
Matching edges and faces in folding/unfolding 3D solids (3 items)	5.Drawing dots on the surfaces of the nets so that the sum of the numbers on two opposite faces equals 7 6.Drawing ribbon segments on the net as attached to the box 7.Determining which edges will meet when the paper is folded	The solid figure is obtained when the paper is folded so that the edge of 1 meets B. Where will 2, 3, 4 and 5 be correspondingly? 
Calculation of the volume and the area (3 items)	8.Finding area of U-shaped figure 9.Finding volume of U-shaped figure 10.Finding the area of colored stripes with overlapping area	Find the area of the yellow and green parts of the figure.  Find the volume of this figure. 
Visualizing rotations of 2D shapes and Orientation (3 items)	11.Identifying 3D solid for rotation of rectangular postcard 12.Identifying 3D solid for rotation of right triangle 13. Identifying direction after clockwise anticlockwise rotation	Which object is formed when right triangle RST is rotated around leg RS ? 

(Adapted from Pittalis & Christou, 2010)