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Modeling mathematical critical thinking and connection abilities as predictors of spatial ability in pre-service mathematics teachers

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ABSTRACT

Spatial ability plays a crucial role in geometry learning, yet its cognitive predictors within higher education contexts remain underexplored. While prior research has established associations between spatial reasoning and mathematical performance, limited studies have examined the combined predictive roles of mathematical critical thinking and mathematical connection abilities within a single regression framework. This study investigates the structural predictive influence of these two cognitive constructs on students' mathematical spatial ability among pre-service mathematics teachers. A quantitative explanatory correlational design was employed, involving all 23 students enrolled in a Spatial Geometry course at UIN Siber Syekh Nurjati Cirebon during the 2025/2026 academic year. The sample represented a census of the accessible cohort, as the entire population meeting the inclusion criteria was included. Data were collected using validated essay-based instruments aligned with established theoretical indicators. Multiple regression analysis was conducted after verifying statistical assumptions. The results indicate that mathematical critical thinking ability significantly predicts mathematical spatial ability ($p = 0.001$), and mathematical connection ability also demonstrates a significant positive predictive role ($p = 0.000$). Jointly, both predictors explain 81.1% of the variance in spatial ability (Adjusted $R^2 = 0.811$). These findings highlight the integrative contribution of analytical reasoning and conceptual linkage processes to spatial cognition and suggest that geometry instruction may benefit from systematically fostering critical thinking and mathematical connections.

INTRODUCTION

The rapid advancement of science and technology in the 21st century requires education systems to design learning environments that cultivate deep conceptual understanding and advanced cognitive competencies. Higher education institutions are expected to prepare students who demonstrate analytical precision, structured reasoning, and creative problem-solving abilities aligned with global academic standards (Zhu et al., 2023). Within mathematics education, the development of higher-order thinking skills is positioned as a central objective because mathematical understanding depends on reasoning, representation, and conceptual integration. Among the cognitive competencies emphasized in contemporary mathematics learning are critical thinking skills, mathematical connection ability, and spatial ability (Mix et al., 2022; Nathan & Walkington, 2022). These three constructs function as interconnected dimensions that shape students' capacity to analyze problems, integrate concepts across representations, and construct coherent mental models of mathematical structures (Lowrie et al., 2023; Mix, 2021).

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Spatial ability occupies a particularly strategic position in mathematics education because it underlies the interpretation and transformation of geometric representations (Battista, 2022) . Spatial ability involves the capacity to visualize objects, mentally rotate figures, perceive spatial relationships, and interpret representations across dimensions (Gilligan-Lee et al., 2023; Harris et al., 2023; Hawes et al., 2022; Verdine et al., 2022). Ramful (2022) classifies spatial ability into five principal components: spatial perception, spatial visualization, mental rotation, spatial relations, and spatial orientation. These dimensions represent structured cognitive processes that enable learners to associate visual representations with abstract mathematical reasoning (Izzati & Farizi., 2025; Lowrie et al., 2023; Resnick & Newcombe, 2023). Empirical findings demonstrate that spatial ability significantly predicts achievement in geometry, trigonometry, and calculus (Poltz et al., 2025; Xu et al., 2025; Zhang & Lin, 2024). Students with strong spatial competence exhibit accuracy in interpreting three-dimensional objects, transforming symbolic expressions into graphical representations, and analyzing geometric configurations (Izzati et al., 2024; Medina Herrera, 2024). Further reports a positive correlation between spatial ability and students' performance in geometric transformations, while Sorby (2022) confirms that spatial competence contributes to overall mathematics achievement. These findings establish spatial ability as a critical cognitive outcome in mathematics learning.

Despite its importance, National and International assessment data indicate that Indonesian students continue to experience difficulties in reasoning and representation-based mathematics tasks. The Pisa (2022) reports that Indonesian students obtained an average mathematics score of 366, considerably below the OECD average of 472. Similarly, the 2019 Trends in International Mathematics and Science Study (TIMSS) highlights persistent challenges in items requiring interpretation of geometric relationships and spatial configurations. These results reflect limitations in conceptual integration, reasoning accuracy, and representational fluency (Mulligan et al., 2021). Such patterns suggest that spatial reasoning remains an area requiring systematic investigation, particularly within mathematics education programs responsible for preparing future teachers (Yang et al., 2024).

Within higher education contexts, students enrolled in mathematics education programs are expected to master geometric visualization, representational transformation, and spatial explanation skills as part of their professional preparation (Izzati & Farizi., 2025).. In the Mathematics Education Study Program at UIN Siber Syekh Nurjati Cirebon, geometry and advanced mathematics courses require students to interpret multidimensional representations and connect symbolic, graphical, and spatial forms. However, learning experiences frequently reveal challenges in mentally rotating objects, identifying spatial relationships, and integrating algebraic expressions with geometric structures. These instructional observations underscore the relevance of examining cognitive predictors that may influence students' spatial ability.

Critical thinking skills represent one cognitive construct that potentially contributes to spatial reasoning development. Ennis (2018) defines critical thinking as disciplined judgment grounded in systematic reasoning, while Facione (2015) operationalizes it into six dimensions: interpretation, analysis, evaluation, inference, explanation, and self-regulation. In mathematical contexts, these processes guide learners in examining geometric structures, evaluating transformation procedures, and drawing logically consistent conclusions (Uttal et al., 2022). Cheng & Mix (2021) emphasize that analytical reasoning supports the identification of structural errors and improves strategic decision-making in problem solving. Lowrie et al (2023) further demonstrate that structured reasoning enhances the interpretation of visual-spatial information. Students with limited critical thinking often depend on algorithmic memorization without conceptual justification (Yanuari, 2023), which restricts their capacity to engage in complex spatial transformations.

Mathematical connection ability also plays a strategic role in supporting spatial cognition. Bower & Liben (2021) explain that connection skills facilitate integration across mathematical topics and representations. The National Council of Teachers of Mathematics (2020) identifies connections as a core process standard that enables learners to recognize relationships among ideas, representations, and structures. Sumarmo (2010) outlines indicators of mathematical connection ability, including intra-topic connections, inter-domain connections, and application to real-life contexts. Empirical studies confirm that students who effectively connect algebraic, graphical, and geometric representations demonstrate stronger conceptual coherence and improved representational flexibility (Hegarty, 2021; Izzati, 2024; Resnick & Newcombe, 2023). Because spatial reasoning requires coordination between symbolic structures and visual representations, mathematical connection ability may function as a cognitive bridge linking abstract reasoning with spatial interpretation. Preliminary observations in geometry courses within the Mathematics Teaching Study Program indicated that some students encountered difficulties in visualizing three-dimensional representations and translating them into formal mathematical reasoning.

Previous research has predominantly examined the relationship between critical thinking skills and mathematics achievement or between mathematical connection ability and problem-solving performance (Gilligan & et al., 2022; Schenck & Nathan, 2024). Other investigations have analyzed spatial ability as an independent predictor of mathematical success (Uttal et al., 2022). However, empirical studies that simultaneously model the structural influence of critical thinking skills and mathematical connection ability on spatial ability remain limited (Lowrie & Logan, 2023; Uttal, 2021). Existing investigations often focus on dual-variable correlations and do not examine how reasoning competencies interact collectively to shape spatial cognition within mathematics education students. This gap restricts comprehensive understanding of the integrated cognitive mechanisms underlying spatial reasoning.

Based on this theoretical and empirical foundation, the present study aims to examine the structural influence of mathematical critical thinking skills and mathematical connection ability on students' spatial ability in the Mathematics Education Study Program at UIN Siber Syekh Nurjati Cirebon. Employing a quantitative correlational framework, this research analyzes the magnitude and direction of relationships among these cognitive constructs. The findings are expected to contribute to theoretical advancement in understanding the integration of reasoning and spatial cognition within mathematics education. Practically, the results are anticipated to inform instructional design that systematically strengthens analytical reasoning, conceptual linkage, and spatial competence in mathematics learning.

Based on the proposed conceptual framework, this study formulates three research hypotheses aligned with multiple regression analysis. First, mathematical critical thinking ability significantly predicts students' mathematical spatial ability. Second, mathematical connection ability significantly predicts students' mathematical spatial ability. Third, mathematical critical thinking ability and mathematical connection ability jointly and significantly predict students' mathematical spatial ability, as reflected in the overall model significance (F-test) and the proportion of explained variance (R^2).

METHODS

This study employed a quantitative approach using an explanatory correlational design to examine the structural relationships between mathematical critical thinking ability, mathematical connection ability, and students' mathematical spatial ability. The design was selected to analyze predictive relationships among variables without implementing instructional interventions or experimental treatments. Accordingly, the study focuses on modeling the magnitude and direction of relationships among constructs within a defined academic cohort.

The population of this study consisted of students enrolled in the Spatial Geometry course in the Mathematics Teaching Study Program at UIN Siber Syekh Nurjati Cirebon during the 2025/2026 academic year. The accessible population comprised one intact class consisting of 23 students. All students who met the inclusion criterion, namely having completed prerequisite geometry coursework, were included in the study. Therefore, the sampling procedure functioned as a census of the accessible cohort rather than purposive or random sampling. Because the total number of students in the defined population was limited and entirely involved, sample size estimation formulas such as Slovin were not applied. The findings are interpreted within the framework of analytical generalization, emphasizing explanation of regression-based relationships within the defined cohort rather than statistical generalization to a broader population. However, given the relatively small sample size, statistical power is inherently limited, and the results should be interpreted with caution. The findings are context-bound and may not be directly generalizable to

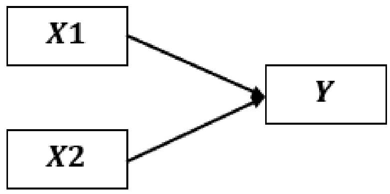

Figure 1. Research conceptual model

larger or different populations. In terms of statistical adequacy, multiple regression analysis involving two predictors can be conducted with small samples provided that the model remains parsimonious and assumptions are satisfied (Hair et al., 2019). Prior to hypothesis testing, diagnostic tests were conducted to ensure that all regression assumptions were fulfilled.

This study examined three variables, namely mathematical critical thinking ability (X_1) and mathematical connection ability (X_2) as independent variables, and mathematical spatial ability (Y) as the dependent variable. The structural relationship investigated in this study positions mathematical critical thinking and mathematical connection abilities as simultaneous predictors of mathematical spatial ability within a multiple linear regression framework. The conceptual model of this relationship is presented in Figure 1.

The relationship among variables is mathematically expressed as:

$$\gamma = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \varepsilon \qquad (1)$$

where Yrepresents mathematical spatial ability, X_1represents mathematical critical thinking ability, X_2 represents mathematical connection ability, β_0 denotes the intercept, β_1 and β_2 represent regression coefficients, and εrepresents the error term.

The instruments used to measure these variables were developed systematically beginning with the identification of theoretical dimensions drawn from established literature, followed by the preparation of a table of specifications to ensure alignment between indicators and test items. The mathematical critical thinking instrument was constructed based on indicators including interpretation, analysis, evaluation, inference, explanation, and self-regulation. Initially, 18 items were developed, and after item analysis, 13 items were retained. The mathematical connection instrument was developed based on indicators covering intra-mathematical connections, connections between mathematical concepts and other disciplines, and the application of mathematics in real-life contexts. From the initial 9 items constructed, 5 items met the validity criteria and were retained. The mathematical spatial ability instrument was developed based on indicators including spatial perception, spatial visualization, mental rotation, spatial relations, and spatial orientation. Of the 9 items initially developed, 6 items were retained following item analysis.

Content validity was established through a structured expert judgment process involving two mathematics education experts who evaluated each item in terms of conceptual relevance, clarity of formulation, and alignment with the intended theoretical constructs. The review also considered cognitive demand and the suitability of spatial and representational prompts to ensure accurate construct representation. Revisions were implemented based on expert feedback, including refinement of wording, adjustment of problem contexts, and clarification of task instructions. The instruments were subsequently pilot-tested with students possessing characteristics comparable to the target cohort to examine empirical item quality. Item validity was analyzed using item–total correlation coefficients to assess each item's contribution to the overall construct, while discrimination indices were calculated to determine the ability of items to differentiate between higher- and lower-performing students. The difficulty index was examined to ensure an appropriate distribution of item complexity. Only items meeting acceptable psychometric criteria were retained in the final instruments. Reliability analysis was then conducted to evaluate internal consistency, and all three instruments demonstrated acceptable reliability levels for explanatory correlational research. Prior to hypothesis testing, the overall quality of the instruments was confirmed through

Table 1
Item validity, reliability, difficulty index, and discrimination power of the mathematical critical thinking ability instrument

Number Questions	Validity		Discrimination Index		Difficulty Level		Remarks
	Score	Criteria	Score	Criteria	Score	Criteria	
1	0.636	Valid	0.399	Good	0.661	Medium	Item Included
2	0.298	Invalid	0.096	Poor	0.652	Medium	Item Excluded
3	0.604	Valid	0.293	Acceptable	0.743	Medium	Item Included
4	0.059	Invalid	0.099	Poor	0.544	Medium	Item Excluded
5	0.241	Invalid	0.023	Poor	0.456	Medium	Item Excluded
6	0.516	Valid	0.499	Good	0.678	Medium	Item Included
7	0.935	Valid	0.334	Good	0.543	Medium	Item Included
8	0.996	Valid	0.277	Acceptable	0.567	Medium	Item Included
9	0.133	Invalid	0.020	Poor	0.741	Medium	Item Exluded
10	0.447	Valid	0.047	Poor	0.367	Difficult	Item Included
11	0.847	Valid	0.443	Good	0.691	Medium	Item Included
12	0.508	Valid	0.311	Good	0.667	Medium	Item Included
13	0.759	Valid	0.347	Good	0.821	Easy	Item Included
14	0.701	Valid	0.142	Poor	0.839	Easy	Item Included
15	0.799	Valid	0.233	Acceptable	0.459	Medium	Item Included
16	0.769	Valid	0.235	Acceptable	0.610	Medium	Item Included
17	0.711	Valid	0.230	Acceptable	0.588	Medium	Item Included
18	0.169	Invalid	-0.027	Poor	0.584	Medium	Item Excluded

Reliability of Critical Thinking Ability Instruments
Cronbach's Alpha = 0.474
Category = Medium

Table 2
Item validity, reliability, difficulty index, and discrimination power of the mathematical connection ability instrument

Number Questions	Validity		Discrimination Index		Difficulty Level		Remarks
	Score	Criteria	Score	Criteria	Score	Criteria	
1	0.824	Valid	0.267	Acceptable	0.670	Medium	Item Included
2	0.534	Invalid	0.080	Poor	0.711	Medium	Item Excluded
3	0.745	Valid	0.090	Poor	0.635	Medium	Item Included
4	0.481	Invalid	0.251	Acceptable	0.622	Medium	Item Excluded
5	0.000	Invalid	0.626	Good	0.707	Medium	Item Excluded
6	0.978	Valid	0.604	Good	0.637	Medium	Item Included
7	0.688	Valid	0.366	Good	0.663	Medium	Item Included
8	0.716	Valid	0.597	Good	0.677	Medium	Item Included
9	0.161	Invalid	0.608	Good	0.700	Medium	Item Excluded

Instrument Reliability Mathematical Connection Ability
Cronbach's Alpha = 0.607
Category = Medium

combined analyses of validity, reliability, difficulty level, and discrimination power, with the results for mathematical critical thinking ability presented in Table 1

As shown in Table 1 all items of the mathematical critical thinking instrument meet the criteria for empirical validity, as indicated by item–total correlation coefficients exceeding the minimum threshold. The reliability coefficient also demonstrates that the instrument possesses satisfactory internal consistency. Furthermore, the distribution of difficulty indices ranges from moderate to acceptable levels, indicating that the items are neither excessively easy nor overly difficult. The discrimination indices reveal that the items are capable of differentiating effectively between high- and low-ability students. Collectively, these results confirm that the mathematical critical thinking

Table 3
Item validity, reliability, difficulty index, and discrimination power of the mathematical spatial ability instrument

Number Questions	Validity		Discrimination Index		Difficulty Level		Remarks
	Score	Criteria	Score	Criteria	Score	Criteria	
1	0.038	Invalid	0.287	Acceptable	0.746	Medium	Item Excluded
2	0.213	Invalid	0.105	Poor	0.724	Medium	Item Excluded
3	0.701	Valid	0.553	Good	0.725	Medium	Item Included
4	0.125	Invalid	0.183	Poor	0.676	Medium	Item Excluded
5	0.857	Valid	0.204	Acceptable	0.664	Medium	Item Included
6	0.654	Valid	0.385	Good	0.727	Medium	Item Included
7	0.690	Valid	0.056	Poor	0.692	Medium	Item Included
8	0.816	Valid	0.355	Good	0.668	Medium	Item Included
9	0.711	Valid	0.395	Good	0.745	Medium	Item Included

Instrument Reliability Mathematical Spatial Ability
Cronbach's Alpha = 0.565
Category = Medium

instrument is psychometrically sound and suitable for use in subsequent regression analyses. Following the analysis of the critical thinking instrument, the same validation procedures were applied to the mathematical connection ability instrument.

Table 2 indicates that all items of the mathematical connection instrument meet the established empirical validity criteria based on item total correlation analysis, confirming that each item contributes meaningfully to the measurement of the intended construct. The reliability coefficient reflects satisfactory internal consistency, indicating that the items function cohesively in assessing students' ability to relate mathematical concepts across representations and domains. The difficulty indices are distributed within an acceptable range, ensuring that the instrument captures varying levels of relational complexity without clustering at extreme levels. Furthermore, discrimination index analysis demonstrates that each item possesses adequate power to differentiate between students with higher and lower levels of mathematical connection ability. Collectively, these psychometric indicators confirm the adequacy and measurement precision of the instrument for assessing relational understanding in mathematics. Subsequently, the instrument designed to measure mathematical spatial ability underwent the same systematic validation and reliability procedures to ensure comparable psychometric rigor across constructs.

As presented in Table 3 the mathematical spatial ability instrument demonstrates acceptable empirical validity across all items. The reliability analysis indicates adequate internal consistency. The difficulty indices suggest a proportional distribution of item complexity, while the discrimination indices confirm that the items function effectively in differentiating students' spatial ability levels. Therefore, the spatial ability instrument fulfills the required psychometric standards for inferential statistical analysis.

Taken together, the overall results indicate that the instruments demonstrate sufficient psychometric robustness to support explanatory multiple regression analysis within the defined cohort. As the study aims to examine predictive structural relationships rather than to inform high-stakes assessment decisions, the observed reliability coefficients were deemed adequate for inferential modeling purposes. Following the comprehensive evaluation of content validity, empirical item validity, reliability, difficulty level, and discrimination power, a systematic item refinement process was undertaken to ensure optimal measurement precision. Items that did not meet the established psychometric thresholds were excluded to enhance construct coherence and statistical reliability. Consequently, only items demonstrating acceptable validity and discrimination indices with appropriate levels of difficulty were retained for subsequent analysis. Table 4 provides a detailed summary of this refinement process, specifying the item-level decisions and identifying which items were retained and which were removed based on the combined psychometric evaluation criteria.

Table 4
Item-level validity results and final item selection

Variable	Retained Items	Removed Items
Mathematical Critical Thinking Ability	1, 3, 6, 7, 8, 10, 11, 12, 13, 14, 15, 16, 17	2, 4, 5, 9, 18
Mathematical Connection Ability	1, 3, 6, 7, 8	2, 4, 5, 9
Mathematical Spatial Ability	3, 5, 6, 7, 8, 9	1, 2, 4

Table 2 presents the distribution of retained and discarded items for each instrument following the validity and item quality analysis. For the mathematical critical thinking instrument, 13 out of 18 items were retained, while 5 items were excluded due to not meeting the established validity criteria or demonstrating insufficient discrimination. In the mathematical connection instrument, 5 items were retained and 4 items were discarded. For the mathematical spatial ability instrument, 6 items were retained, and 3 items were excluded from the final version of the test.

The exclusion of certain items was based on statistical considerations, including item-total correlation values below the required threshold and weak discrimination indices. The retained items collectively represent the theoretical dimensions specified in the instrument blueprint, ensuring that the construct coverage remained intact despite item reduction. This refinement process strengthens the internal consistency of the instruments and enhances the accuracy of measurement used in subsequent regression analysis.

All instruments were administered within the same instructional topic, namely Spatial Geometry, to ensure construct consistency across variables. However, the three tests were conducted across three separate class meetings to minimize fatigue effects and reduce potential testing bias. Each test session lasted approximately 90 minutes and was administered under standardized classroom conditions. Conducting the tests within the same topic ensured that all measured variables reflected mastery within the same content domain, thereby strengthening the internal validity of the regression analysis and minimizing the risk that differences in subtopic exposure would affect the interpretation of relationships among variables.

Data were analyzed using multiple linear regression at a significance level of 0.05 to examine both partial and simultaneous effects of mathematical critical thinking ability and mathematical connection ability on students' mathematical spatial ability. Prior to conducting hypothesis testing, regression assumptions were evaluated, including normality using the Kolmogorov–Smirnov test and P–P plot, multicollinearity using tolerance and variance inflation factor values, and homoscedasticity using scatterplot and Glejser test procedures. The diagnostic results indicated that all assumptions were satisfied, confirming that the regression model was appropriate for examining the proposed relationships.

FINDINGS

Descriptive statistics of variables and their dimensions

The results of the data analysis showed clear differences in the levels of students' mathematical critical thinking skills, mathematical connection skills, and mathematical spatial skills. These variations were identified through descriptive statistical analysis, which provided an overview of each variable's characteristics, including the mean score, score range, and standard deviation. The findings illustrate that while students generally achieved relatively high scores, there was still considerable diversity in their performance, reflecting differences in their ability to think critically, establish conceptual linkages, and visualize spatial relationships. This descriptive stage serves as the foundation for further inferential analysis, ensuring that subsequent regression testing is conducted on data whose initial distribution and variability have been well understood.

Table 5 presents the descriptive statistical results of the three research variables. Students' mathematical critical thinking skills recorded an average score of 77.044, with a score range between 63.000 and 88.000, and a standard deviation of 6.470. The mathematical connection ability showed

Table 5
Description of students' mathematical ability statistics

	N	Minimum	Maximum	Red	Standard Deviation	Variance
Critical Thinking Skills	23	63.000	88.000	77.044	6.470	41.862
Mathematical Connection Capabilities	23	65.000	85.000	75.304	6.449	41.585
Mathematical Spatial Ability	23	63.000	94.000	81.217	7.983	63.723
Valid N (*listwise*)	23					

Table 6
Description of dimension mathematical critical thinking ability

	N	Minimum	Maximum	Mean	Standard Deviation	Variance
CT_Interpretation	23	3.333	8.000	5.710	1.488	2.215
CT_Analysis	23	1.000	11.000	5.957	2.602	6.771
CT_Evaluation	23	2.500	9.500	5.827	1.807	3.264
CT_Inference	23	1.000	9.500	6.000	2.241	5.023
CT_Explanation	23	2.500	11.000	6.260	2.325	5.406
CT_SelfRegulation	23	3.000	10.333	5.840	1.654	2.736
Valid N (listwise)	23					

an average score of 75.304, with a minimum score of 65.000 and a maximum score of 85.000, accompanied by a standard deviation of 6.449. Meanwhile, mathematical spatial ability obtained a mean score of 81.217, with a score range between 63.000 and 94.000, and a standard deviation of 7.983. While Table 1 summarizes the overall descriptive statistics of each research variable based on standardized scores ranging from 0 to 100, a more detailed examination at the dimensional level is necessary to understand the distribution of students' performance within each construct. The following analysis presents the descriptive statistics of each dimension of mathematical critical thinking ability based on the original scoring rubric prior to score transformation. This approach allows a clearer interpretation of students' performance patterns across the conceptual indicators that form the overall construct.

Table 6 presents the descriptive statistics for each dimension of mathematical critical thinking ability based on the original scoring rubric prior to score standardization. The mean scores across dimensions range from 5.710 to 6.260. The highest average score is observed in the explanation dimension (M = 6.260, SD = 2.325), followed by inference (M = 6.000, SD = 2.241). The interpretation (M = 5.710, SD = 1.488), evaluation (M = 5.827, SD = 1.807), and self-regulation (M = 5.840, SD = 1.654) dimensions show relatively comparable central tendencies. The analysis dimension records a mean of 5.957 with the largest variability (SD = 2.602), indicating greater dispersion of student performance within this indicator.

Overall, the distribution of mean scores across dimensions appears relatively balanced, suggesting that students' mathematical critical thinking ability is distributed across its conceptual components without extreme dominance in a single dimension. These findings provide a more granular depiction of the construct prior to subsequent inferential analysis. Following the dimensional analysis of mathematical critical thinking ability, a similar descriptive examination was conducted for each dimension of mathematical connection ability.

Table 7 presents the descriptive statistics for each dimension of mathematical connection ability based on the original scoring rubric prior to score transformation. The mean scores across the three dimensions range from 14.956 to 15.043, indicating relatively comparable central tendencies. The highest mean is observed in the dimension of connections among mathematical concepts (M = 15.043, SD = 2.168), followed closely by connections across mathematical topics (M = 14.978, SD = 2.075). The dimension of connections between mathematics and real-life contexts records a mean of 14.956 with the largest dispersion (SD = 3.254), suggesting greater variability in students' performance within this indicator.

Table 7

Description of dimension mathematical connection ability

	N	Minimum	Maximum	Mean	Standard Deviation	Variance
MC_Connections Between Concepts	23	10.500	21.000	15.043	2.168	4.703
MC_ Connections Between Studies	23	11.000	19.000	14.978	2.075	4.306
MC_Koneksi With Life	23	4.000	19.000	14.956	3.254	10.589
Valid N (listwise)	23					

Table 8

Description of dimension mathematical spatial ability

	N	Minimum	Maximum	Mean	Standard. Deviation	Variance
MS_SpatialOrientation	23	9.670	16.670	12.971	2.040	4.161
MS_MentalOrientation	23	8.500	17.000	13.804	2.125	4.517
MS_Visualization	23	8.000	19.000	14.565	2.694	7.257
Valid N (listwise)	23					

The relatively similar mean values across dimensions indicate that students' mathematical connection ability is distributed proportionally among conceptual, inter-topic, and contextual linkages. This dimensional overview provides a detailed characterization of the construct prior to examining its relationship with other research variables. After examining the dimensional structure of mathematical connection ability, the descriptive analysis was continued for each dimension of mathematical spatial ability.

Table 8 presents the descriptive statistics for each dimension of mathematical spatial ability based on the original scoring rubric prior to standardization. The mean scores range from 12.971 to 14.565. The highest mean is observed in the visualization dimension (M = 14.565, SD = 2.694), followed by mental orientation (M = 13.804, SD = 2.125), while spatial orientation records the lowest mean (M = 12.971, SD = 2.040). The visualization dimension also demonstrates the largest variability among the three indicators (SD = 2.694), indicating relatively greater dispersion in students' performance within this component. The distribution of mean scores across dimensions suggests a differentiated yet proportionate pattern of spatial performance, with visualization emerging as the dimension showing comparatively stronger central tendency. This dimensional analysis provides a detailed profile of students' spatial ability prior to examining its structural relationship with critical thinking and mathematical connection abilities. Having described the distribution of each variable and its dimensions, the analysis proceeded to examine the bivariate relationships among the research variables through Pearson correlation analysis.

Correlation analysis

Following the descriptive examination of each variable and its dimensions, a Pearson correlation analysis was conducted to investigate the bivariate relationships among mathematical critical thinking ability, mathematical connection ability, and mathematical spatial ability. This analysis was intended to determine the direction, strength, and statistical significance of the linear associations between variables prior to performing multiple linear regression analysis.

The results of the Pearson correlation analysis are presented in Table 9. The analysis indicates that mathematical critical thinking ability is positively and significantly correlated with mathematical spatial ability ($r = 0.754$, $p < 0.01$). This coefficient reflects a strong linear association, suggesting that higher levels of critical thinking ability are associated with higher levels of spatial ability. Similarly, mathematical connection ability demonstrates a strong positive and statistically significant correlation with mathematical spatial ability ($r = 0.828$, $p < 0.01$). The magnitude of this coefficient indicates a very strong linear relationship between the two variables. In addition, mathematical critical thinking ability is moderately correlated with mathematical connection ability ($r = 0.522$, $p <$

Table 9
Pearson correlation matrix of research variables

		Mathematical Critical Thinking Ability	Mathematical Connection Ability	Mathematical Spatial Ability
Mathematical Critical Thinking Ability	Pearson Correlation	1	0.522	0.754
	Sig. (2-tailed)		0.011	0.000
	N	23	23	23
Mathematical Connection Ability	Pearson Correlation	0.522	1	0.828
	Sig. (2-tailed)	0.011		0.000
	N	23	23	23
Mathematical Spatial Ability	Pearson Correlation	0.754	0.828	1
	Sig. (2-tailed)	0.000	0.000	
	N	23	23	23

0.05), indicating that the two independent variables are related but not excessively correlated. The correlation values among predictors remain below commonly accepted multicollinearity thresholds, supporting the appropriateness of subsequent multiple regression analysis. Overall, these findings confirm the presence of significant linear relationships among the research variables, thereby providing preliminary empirical support for the proposed hypotheses and justifying further inferential modeling.

Assumption testing of multiple linear regression

Following the confirmation of statistically significant bivariate relationships through Pearson correlation analysis, the next analytical stage involved systematically examining the assumptions required for multiple linear regression to ensure the robustness of parameter estimation and the validity of inferential conclusions. Assumption testing constitutes a critical prerequisite in regression modeling, as violations may lead to biased coefficient estimates, unstable standard errors, and misleading significance tests. Therefore, prior to estimating the regression equation, diagnostic procedures were conducted to verify that the data satisfied the core statistical requirements of the model. The assessment began with a normality test to evaluate whether the residuals approximated a normal distribution, which underpins the reliability of t-tests and F-tests in parametric regression analysis. Evaluating normality at the residual level is particularly important in explanatory correlational research, as it supports accurate hypothesis testing and confidence interval estimation. By conducting this diagnostic step before proceeding to the full regression model, the analysis ensured that the data structure and error distribution were appropriate for predictive modeling within the defined cohort.

The visual assessment of residual normality was conducted using the Normal P–P Plot, as presented in Figure 2. As illustrated in Figure 2, the standardized residual points are distributed closely along the diagonal reference line without exhibiting substantial deviations. This pattern indicates that the residuals are approximately normally distributed. This visual pattern reflects that the regression residuals have a distribution close to normal, and the consistency of the points around the reference line indicates that there is no violation of the normality assumption in the regression model used. To reinforce these visual findings, statistical testing of residual normality was conducted using the Kolmogorov–Smirnov test. The Kolmogorov–Smirnov test generated a Sig. (2-tailed) value of 0.200, which exceeds the 0.050 significance threshold, confirming that the residuals follow a normal distribution. Consequently, the fulfillment of the normality assumption is validated through both visual inspection of the P–P Plot and statistical verification via the Kolmogorov–Smirnov test, ensuring that the regression model satisfies the normality prerequisite and can be appropriately applied in the subsequent multiple linear regression analysis.

The Kolmogorov–Smirnov normality test on standardized residuals, as shown in Table 10, produced an Sig. (2-tailed) value of 0.200, which exceeds the 0.050 significance threshold. This result confirms that the regression residuals follow a normal distribution, thereby fulfilling the normality assumption as a key prerequisite in multiple linear regression analysis. With this assumption met, the analysis proceeded to the multicollinearity test, which is designed to verify that no strong linear

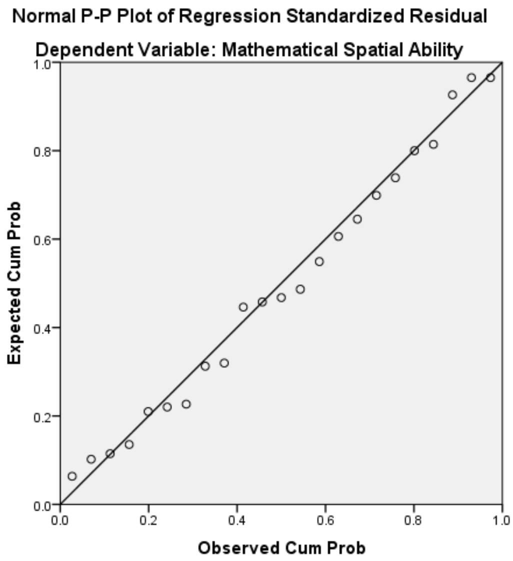

Figure 2. P-P Normality Test

Table 10
Ausmis test results of residual normality regression model

Variabel	N	Test Statistic	Sig.(2-tailed)	Remarks
Unstandardized Residual	23	0.089	0.200	Normal Distribution

Table 11
Multicollinearity indicator between variables

Independent Variables	Tolerance	VIF
Mathematical Critical Thinking Ability	0.728	1.374
Mathematical Connections Ability	0.728	1.374

correlation exists among the independent variables, since excessive multicollinearity can bias regression coefficients, weaken statistical accuracy, and complicate interpretation. The results of the multicollinearity test shown in Table 11 reveal that the independent variables mathematical critical thinking skills and mathematical connection skills possess tolerance values greater than 0.100 and Variance Inflation Factor (VIF) values less than 10.000. These outcomes confirm that the regression model does not experience multicollinearity problems and that the independence assumption among predictors is fulfilled, thereby ensuring the reliability of the regression analysis. Consequently, with both normality and multicollinearity assumptions fulfilled, the regression model is considered valid and reliable for subsequent hypothesis testing using multiple linear regression.

Multicollinearity was examined using Tolerance and Variance Inflation Factor (VIF) values, as presented in Table 11. The results indicate that both independent variables mathematical critical thinking ability and mathematical connection ability have a tolerance value of 0.728 and a VIF value of 1.374. These values exceed the minimum tolerance threshold of 0.10 and remain well below the commonly accepted VIF cutoff of 10, indicating that multicollinearity is not present in the regression model. A *Tolerance value* that exceeds the threshold of 0.100 indicates that the portion of variance of each independently standing independent variable is at a sufficient level. Correspondingly, a VIF value well below the 10,000 limit indicates the absence of significant linear linkages between independent variables in the regression model. These findings confirm that both independent variables are feasible to be analyzed simultaneously in multiple linear regression without affecting the accuracy of the coefficient estimates. This situation reflects the stability of the regression parameters and the absence of overlapping information between predictor variables. With the

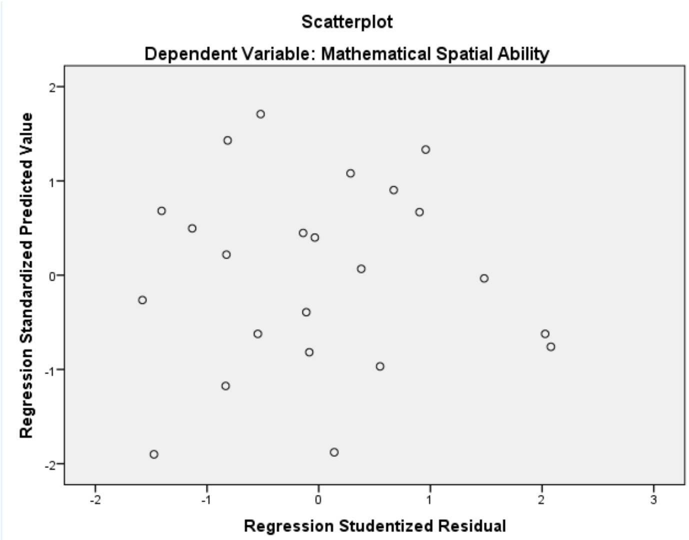

Figure 3. Scatterplot method Heteroscedasticity Test

Table 12
Results of residual variance heteroscedasticity test (Glejser method)

Models		B	Std. Error	Beta	t	Sig.	Collinearity Statistics Tolerance	VIF
1	(Constant)	5.545	5.773		0.960	0.348		
	Mathematical Critical Thinking Ability	-0.035	0.077	-0.117	-0.450	0.658	0.728	1.374
	Mathematical Connection Ability	-0.003	0.077	-0.010	-0.040	0.968	0.728	1.374

fulfillment of the multicollinearity assumption, the contribution of each independent variable to the bound variable can be analyzed independently and objectively. Based on these findings, the multiple linear regression prerequisite test was then followed by a heteroscedasticity test to assess the uniformity of residual variance as one of the indicators of the feasibility of the regression model used.

Heteroscedasticity testing was conducted to examine the uniformity of residual variance in the multiple linear regression model. The scatterplot of standardized residuals is presented in Figure 3. Preliminary examination through *scatterplot* analysis between standardized residual and predicted values showed a random distribution of data points spread around the zero line. The distribution pattern does not show any specific tendencies, such as clustering, narrowing, or widening it, indicating that the residual variance is relatively homogeneous across the entire range of predicted values. These findings show no visual indication of heteroscedasticity in the regression model applied.

To obtain more objective certainty, heteroscedasticity testing was then continued through a statistical approach using the Glejser test. This test aims to identify the existence of a significant relationship between absolute residual values and independent variables. The results of the Glejser test are used as a basis for strengthening the visual findings on the *scatterplot*, so that the conclusion regarding the fulfillment of the heteroscedasticity assumption in the regression model can be established more convincingly.

The heteroscedasticity assumption was further examined using the Glejser test, and the results are presented in Table 12. As shown in Table 12, the significance values for mathematical critical thinking ability and mathematical connection ability are 0.658 and 0.968, respectively. Since both values exceed the 0.05 significance threshold, the results indicate that heteroscedasticity is not present in the regression model. The significance value above the 0.050 level indicates that the regression model meets the assumption of homogeneity. These results confirm that the residual variance is homogeneous and does not depend on changes in the value of the independent variables

Table 13
Simultaneous regression model feasibility test

Models		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	1160.717	2	580.358	48.123	0.000
	Residual	241.197	20	12.060		
	Total	1401.913	22			

Table 14
Partial influence of mathematical critical thinking ability and mathematical connection ability on mathematical spatial ability

Models		B	Std. Error	Beta		
1	Constant	-16.510	10.038		-1.645	0.116
	Mathematical Critical Thinking Ability	0.546	0.134	0.443	4.073	0.001
	Mathematical Connection Ability	0.739	0.135	0.597	5.491	0.000

analyzed. This consistency strengthens the quality of the regression model used. These results are in line with other assumption tests, namely normality tests that indicate residual distributions follow normal patterns and multicollinearity tests that show the absence of strong linear relationships between independent variables. With the fulfillment of all the basic assumptions of multiple linear regression statistically, the analysis model is declared feasible for use at the hypothesis testing stage. The completion of all prerequisite analyses serves as the foundation for examining the influence of independent variables on the dependent variable through multiple linear regression. The first stage of this analysis was conducted using the F test to evaluate the overall significance of the regression model. This procedure is intended to determine whether mathematical critical thinking skills and mathematical connection skills jointly provide a significant contribution to students' spatial abilities, prior to advancing to the partial testing of each variable individually.

The results of the simultaneous significance test (F-test), as presented in Table 13, show an F value of 48.123 with a significance level of 0.000 ($p < 0.05$). This finding indicates that mathematical critical thinking ability and mathematical connection ability collectively serve as statistically significant predictors of students' mathematical spatial ability within the multiple linear regression model. The statistical significance of the F-test confirms that the model provides a meaningful explanation of variations in spatial ability. Therefore, the third hypothesis (H_3) is accepted. Following the confirmation of the model's simultaneous significance, a partial significance test (t-test) was performed to evaluate the individual predictive contribution of each independent variable, as shown in Table 14.

The results of the partial significance tests (t-tests) are presented in Table 14. As shown in Table 14, mathematical critical thinking ability obtained a significance value of 0.001 ($p < 0.05$), indicating that it serves as a statistically significant predictor of students' mathematical spatial ability. The positive regression coefficient further suggests that higher levels of critical thinking ability are associated with higher levels of spatial ability. Therefore, the first hypothesis (H_1) is accepted. In addition, mathematical connection ability also demonstrated a statistically significant effect on students' mathematical spatial ability, with a significance value of 0.000 ($p < 0.05$). The positive regression coefficient indicates that students' ability to establish mathematical connections is positively associated with variations in spatial ability. Accordingly, the second hypothesis (H_2) is accepted.

The results of multiple linear regression analysis produce regression model equations that can be formulated as follows:

$$Y = -16.510 + 0.546X_1 + 0.739X_2 \quad (2)$$

Table 15
Determination coefficient

Models	R	R Square	Adjusted R Square	Std. Error
1	0.910	0.828	0.811	3.47273

Table 16
Summary of hypothesis testing result

Hypothesis	Predictor(s)	Statistical Test	Sig. Value	Decision	Interpretation
H_1	Mathematical Critical Thinking Ability → Mathematical Spatial Ability	t-test	0.001	Accepted	Significant positive predictor
H_2	Mathematical Connection Ability → Mathematical Spatial Ability	t-test	0.000	Accepted	Significant positive predictor
H_3	Mathematical Critical Thinking & Mathematical Connection Abilities → Mathematical Spatial Ability	F-test	0.000	Accepted	Model statistically significant

in the regression model analyzed, the dependent variable (Y) represents mathematical spatial ability, while the independent variables (X_1) and (X_2) describe mathematical critical thinking ability and mathematical connection ability, respectively. A constant value of 16.510 indicates an estimate of mathematical spatial ability when the two independent variables are at zero. The regression coefficient for mathematical critical thinking ability was positive of 0.546, indicating that each one-unit increase in mathematical critical thinking ability was followed by an increase in mathematical spatial ability by 0.546 units, assuming other independent variables were under a fixed condition.

The regression coefficient of mathematical connection ability of 0.739 indicates a positive relationship with mathematical spatial ability. The value of the coefficient indicates that each one unit increase in mathematical connection ability is followed by an increase in mathematical spatial ability by 0.739 units, assuming the other independent variables are at a fixed condition. These results show that mathematical critical thinking skills and mathematical connection skills make a positive contribution to predicting students' mathematical spatial abilities through the applied multiple linear regression model.

The coefficient of determination results are presented in Table 15. As shown in Table 15, the regression model yields an Adjusted R Square value of 0.811. This indicates that approximately 81.1% of the variance in students' mathematical spatial ability can be explained collectively by mathematical critical thinking ability and mathematical connection ability within the model. The remaining 18.9% of the variance is attributable to other factors not included in this study. These results from the multiple linear regression analysis confirm that both independent variables play a significant role in explaining students' mathematical spatial ability. The strength of the relationship reflected in the regression model provides a firm empirical foundation for deeper exploration of the meaning of these findings within the context of mathematics learning. Accordingly, the subsequent discussion is directed toward interpreting these results in relation to the theoretical framework, previous research outcomes, and their implications for designing learning approaches that foster the enhancement of students' mathematical spatial skills. To provide a concise overview of the regression findings, Table 16 summarizes the results of hypothesis testing, including the statistical tests and corresponding decisions.

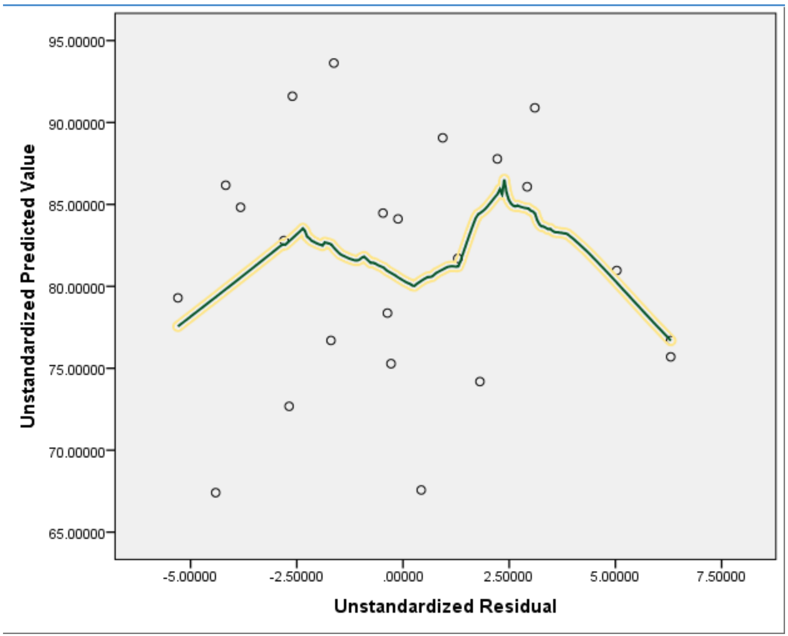

Figure 4. Regression diagnostic graph

DISCUSSION

The findings indicate that mathematical critical thinking ability and mathematical connection ability are significant predictors of students' mathematical spatial ability. These results suggest that spatial ability is not merely a perceptual skill, but is cognitively grounded in higher-order reasoning processes and relational understanding within mathematics. Spatial performance appears to emerge from structured analytical thinking and the integration of conceptual relationships rather than from isolated visualization skills.

The significant predictive role of mathematical critical thinking ability supports the view that analytical reasoning, evaluation of arguments, and logical inference contribute to the construction of accurate mental representations. Students who demonstrate stronger critical thinking skills are more likely to analyze spatial configurations systematically, evaluate solution strategies, and reflect on the validity of their reasoning (Bruce et al., 2023). This interpretation aligns with theoretical perspectives on critical thinking proposed by Ennis (2018) and Facione (2015), which conceptualize critical thinking as a core component of higher-level cognitive processing. Empirically, the present finding is consistent with recent regression-based studies indicating that reasoning abilities significantly predict performance in spatial and geometric tasks (Lowrie & Logan, 2023). The result therefore confirms that spatial ability is cognitively intertwined with structured reasoning processes.

Similarly, the significant predictive role of mathematical connection ability indicates that students' capacity to relate concepts across mathematical domains and representations contributes meaningfully to spatial understanding. The ability to coordinate algebraic, geometric, symbolic, and visual representations appears to facilitate flexible cognitive transitions that support spatial reasoning processes. This finding is consistent with broader empirical evidence demonstrating a positive association between spatial skills and mathematical performance across domains, including regression-based analyses highlighting the predictive role of spatial reasoning in mathematics achievement (Xu et al., 2025). Moreover, meta-analytic syntheses have reported robust positive relationships between spatial abilities and mathematical performance, reinforcing the interpretation that representational and relational processes contribute meaningfully to mathematical cognition (Atit et al., 2022). While many prior studies emphasize spatial reasoning as a predictor of mathematics outcomes, the present study extends this line of research by demonstrating that mathematical connection ability, as a relational construct internal to mathematics, retains a unique predictive contribution to spatial ability within a simultaneous regression framework.

The joint significance of mathematical critical thinking and mathematical connection abilities further suggests that spatial ability reflects coordinated higher-order cognitive functioning rather than isolated visualization skills. Multivariate research in mathematics education increasingly supports the view that multiple cognitive constructs collectively explain substantial variance in complex mathematical performance. The present findings align with this perspective, as meta-analytic evidence indicates that spatial and mathematical abilities are systematically interrelated across diverse samples (Atit et al., 2022). However, by modeling mathematical critical thinking and connection abilities simultaneously within a single regression framework, this study extends prior regression-based research by demonstrating how analytical reasoning and conceptual linkage jointly account for substantial variation in spatial ability among pre-service mathematics teachers. The relatively high proportion of explained variance indicates that, within this bounded higher-education context, spatial competence is strongly associated with coordinated reasoning and representational integration processes rather than isolated visualization skills (Oliveira et al., 2023). This integrative relationship is conceptually represented in Figure 4, which illustrates the structural model derived from the regression analysis. The model emphasizes the complementary and mutually reinforcing roles of critical reasoning and mathematical connections in shaping students' spatial performance.

From a theoretical perspective, these findings contribute to the understanding of spatial ability as a higher-order mathematical construct shaped by reasoning and representational integration. Spatial cognition in mathematics can therefore be conceptualized as an outcome of coordinated analytical and relational processes. Practically, the results suggest that the development of spatial ability may benefit from instructional emphases that cultivate critical reasoning and encourage meaningful connections among mathematical representations. Importantly, these implications are derived from relational findings rather than from experimental intervention, and therefore should be interpreted within the correlational scope of the present study.

CONCLUSIONS

This study demonstrates that mathematical critical thinking ability and mathematical connection ability are significant predictors of students' mathematical spatial ability. Both variables individually contribute to variations in spatial performance, and their simultaneous effect indicates that spatial ability develops through the integration of analytical reasoning and conceptual linkage processes. These findings position spatial ability not merely as a perceptual skill, but as a higher-order cognitive construct grounded in structured reasoning and relational understanding.

The results imply that efforts to strengthen students' spatial ability should emphasize the cultivation of critical analysis, logical evaluation, and meaningful connections among mathematical representations. Enhancing these higher-order cognitive processes may indirectly support the development of spatial competence within mathematics learning contexts. The findings therefore contribute to a more integrated understanding of how reasoning and representational coherence shape spatial cognition.

This study is limited by its cross-sectional design and relatively small sample size, which restrict causal interpretation and generalizability. Future research may employ longitudinal designs to examine how the interaction between critical thinking, mathematical connections, and spatial ability develops over time across different academic levels. Such investigations could clarify whether improvements in reasoning and relational understanding precede and predict growth in spatial competence, thereby providing a more comprehensive explanation of the developmental trajectory of spatial cognition in mathematics.

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	manuscript drafting, revision of the manuscript, and final approval of the version to be published.
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APPENDIX A. Mathematical Critical Thinking Test

1. A cuboid measures 8 cm in length, 5 cm in width, and 4 cm in height. Explain how the relationship among these three dimensions determines the shape and proportions of the cuboid.
2. Two cuboids have the following dimensions:
   - Cuboid A: 8 × 6 × 4 cm
   - Cuboid B: 12 × 4 × 4 cm

   Determine which cuboid has the greater volume and justify your answer mathematically.
3. Calculate the volume of the cuboid measuring 10 × 8 × 6 cm. Then verify your calculation process and confirm the accuracy of the result.
4. A cube has an edge length of 10 cm. The edge length is increased to 12 cm. Explain how this change affects the volume and surface area of the cube.
5. A cube is rotated 90° about its vertical axis. Analyze how this rotation affects the orientation of its faces relative to an observer.
6. A cuboid measuring 20 cm × 10 cm × 5 cm is used as a water container. Based on its capacity, explain the relationship between its dimensions and its volume.
7. Two cuboids have the following dimensions:
   - Cuboid A: 8 × 6 × 4 cm
   - Cuboid B: 12 × 4 × 4 cm

   Explain mathematically the difference in both volume and surface area between the two cuboids, even though they share some identical dimensions.
8. A student writes the volume of a cube using the formula $V = 4s^3$. Evaluate whether this formula is correct and provide mathematical justification for your answer.
9. A net of a cube is given with different face arrangements. Determine whether the net can be folded into a valid cube and justify your reasoning mathematically.
10. Two cuboids have different volumes but appear similar in shape. Compare their characteristics and explain mathematically the differences in their dimensional proportions.
11. Two cuboids have the same volume but different dimensions. Determine whether they necessarily have the same surface area and justify your answer mathematically.
12. A cuboid is rotated about its space diagonal. Make mathematical inferences about the position of the base plane after rotation and explain its orientation relative to the original plane.
13. A cuboid undergoes changes in length and width while its height remains constant. Explain how these simultaneous changes affect both its volume and surface area.

APPENDIX B. Mathematical Connection Test

1. A cuboid measures 10 cm in length, 6 cm in width, and 4 cm in height. Determine its surface area and volume. Then explain how a change in the length of one edge affects both the surface area and the volume of the cuboid.
2. Consider a structural model of a carbon-chain molecule arranged in a cuboid lattice structure, where each carbon atom is connected by parallel bonds forming the edges of the structure. The distance between adjacent atoms along each edge is 2 units. If the structure consists of 4 atoms along its length, 3 atoms along its width, and 2 atoms along its height, determine the longest bond distance between the two farthest atoms in the structure. Explain your reasoning mathematically.
3. A cuboid measures 12 cm in length, 8 cm in width, and 5 cm in height. If its mass is 2.4 kg, determine its density. Explain how the mathematical concept of volume is related to the physical concept of density.
4. Design a cuboid-shaped bookshelf model with a volume of 0.2 m^3. Determine proportional values for its length, width, and height. Then explain the mathematical reasoning behind your choice of dimensions, considering proportionality and efficiency for indoor use.
5. A company plans to produce two types of packaging:
   - one in the shape of a cube, and
   - one in the shape of a cuboid

   both with a volume of 1000 cm^3. Determine the dimensions of each package so that they have the same volume. Then compare their surface areas and explain which design is more efficient in terms of material usage.

APPENDIX C. Mathematical Spasial Ability Test

1. An observer stands in front of a large cube with an "X" marked on its front face. If the observer moves to the right side of the cube, describe the position of the face marked "X" from the new viewing position.
2. Two images of cubes are shown in different orientations. Determine whether the two cubes are congruent. Justify your answer based on the parallel relationships among their faces and edges.
3. A cuboid $ABCD.EFGH$ is observed from the front, producing a rectangular view with edge AB at the bottom and edge AE on the left. If the observer moves above the cuboid, describe how the visible faces change and identify which face becomes visible at the front from the new position.
4. A plane α intersects a cube along edges AB, BC, and CG. Describe the shape of the cross-section formed by this intersection and justify your answer mathematically by analyzing the relative positions of the intersected edges.
5. In three-dimensional space, a line PQ, a line RS, and a plane ABC are given. Using their coordinate representations, determine:
   - the positional relationship between line PQ and plane ABC (parallel, perpendicular, or intersecting), and
   - the positional relationship between line PQ and line RS (parallel, intersecting, or skew).

   Provide mathematical justification for your conclusions.
6. A cuboid $ABCD.EFGH$ has dimensions 8 cm × 6 cm × 4 cm. The cuboid is rotated 180° about the axis passing through edge AE. Determine the position of face $BCFG$ after the rotation and describe its orientation relative to its original position.