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Exploring the Link Between Students' Spatial Reasoning Skills and Academic Performance in Geometry Problem Solving

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ABSTRACT

This study examined the association between students' spatial reasoning skills and academic performance in geometry problem solving. A quantitative descriptive-correlational design was used with 300 randomly selected Grades 7–10 students from three public schools in the Schools Division of Sorsogon City. Data were gathered through a researcher-developed questionnaire assessing spatial visualization, spatial relationships, spatial orientation, application of spatial reasoning, and preferred teaching strategies, supplemented by students' recorded geometry grades. Frequency, percentage, mean, standard deviation, Kruskal–Wallis H, Mann–Whitney U, and Spearman rho were used to analyze the data. The largest proportion of students obtained Fairly Satisfactory grades (42.3%). Spatial visualization (M = 2.62), spatial relationships (M = 2.62), and spatial orientation (M = 2.57) were generally rated High, although pre-visualizing figures, solving complex relational problems, and changing viewpoints were weaker areas. Students reported often applying spatial reasoning (M = 2.68) and favored manipulatives and spatial puzzles. Differences across age, sex, and grade groups were statistically significant in the reported tests ($p < .001$). Geometry performance was strongly and positively correlated with spatial visualization ($\rho = .823$), spatial relationships ($\rho = .833$), and spatial orientation ($\rho = .833$), all $p < .001$. These findings informed the proposed Spatial Reasoning Enhancement in Geometry, emphasizing concrete-to-abstract tasks, differentiated support, and ongoing monitoring. The observed associations do not establish causality.

Keywords: *spatial reasoning; geometry problem solving; spatial visualization; spatial orientation; mathematics achievement; curriculum enhancement*

INTRODUCTION

Spatial reasoning enables learners to interpret, manipulate, and coordinate visual and geometric information. Its principal dimensions—spatial visualization, spatial relationships, and spatial orientation—are central to recognizing figures, interpreting transformations, estimating positions, and solving problems involving two- and three-dimensional objects. Because geometry requires reasoning about both images and mathematical properties, students may struggle even when they know procedures but cannot mentally represent the figures involved (Fujita et al., 2020; Xu et al., 2025).

The relationship between spatial thinking and mathematical achievement has attracted considerable attention. Meta-analytic studies show robust associations between spatial skills and mathematics, while intervention research suggests potential benefits of spatial training that depend on task and implementation conditions (Atit et al., 2022; Hawes et al., 2022). Spatial learning opportunities therefore merit attention alongside

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conventional geometry teaching. Sorby and Panther (2020) likewise emphasized the educational importance of developing spatial skills during schooling.

In the Philippine secondary-school context, the thesis identified challenges in helping learners move beyond recognition of basic shapes toward mental rotation, multi-step relational reasoning, and geometry problem solving. These skills are particularly relevant in junior high school, where learners encounter a broader range of transformations, coordinate problems, nets, and composite figures. The local need was to establish which spatial competencies students reported confidently, which remained difficult, and how these patterns related to their recorded geometry performance.

The present study addressed this need through an assessment of Grades 7–10 students in Filomena D. Deramas Integrated School, Salvacion National High School, and Rawis National High School. It described the students' characteristics and geometry grades, assessed spatial reasoning across three dimensions, examined their reported applications and favored instructional strategies, and tested group differences and relationships with academic performance. The resulting evidence was used to prepare a proposed Spatial Reasoning Enhancement in Geometry for classroom and school-level use. Its emphasis was on association and educational planning rather than proof that any instructional intervention had already improved achievement.

Literature Review

Spatial Reasoning as a Foundation for Geometry Problem Solving

Spatial reasoning involves forming, modifying, and interpreting mental representations as well as understanding how geometric properties remain related when orientation or representation changes. Fujita et al. (2020) found that solving tasks with two-dimensional depictions of three-dimensional objects requires both visual manipulation and explicit knowledge of geometry; reliance on surface appearance alone can be misleading. Ceylan and Bulut (2023) similarly examined learners' handling of spatially demanding real-world problems and identified difficulties translating visualized ideas into solutions.

Research across mathematical domains reinforces this connection. Xu et al. (2025) reported that distinct spatial constructs contribute to performance in numerical, geometric, measurement, and data tasks among elementary learners. Duffy et al. (2024) highlighted the part played by mental representation in mathematics word-problem solving, while Ma'rifatin et al. (2019) addressed the links between mathematical ability and spatial reasoning in geometry. Together these studies indicate that geometry instruction should combine visual interpretation, analytic explanation, and active transformation of representations.

Cognitive approaches further help explain the need for balanced instruction. Cognitive load theory emphasizes managing the demands imposed on working memory when learners process complex representations (Sweller et al., 2021). In the thesis, this theoretical perspective is paired with dual coding: visual diagrams, physical models, and verbal explanations can jointly support the interpretation of abstract concepts. Consequently, the present inquiry considers multiple spatial dimensions rather than treating spatial ability as a single classroom skill.

Spatial Ability and Academic Performance

A broad evidence base has established spatial ability as a correlate of mathematical proficiency. Atit et al. (2022), in a meta-analysis, examined relationships between spatial and mathematics performance; Hawes et al. (2022) separately assessed whether spatial training transfers to mathematics outcomes. These findings support attention to spatial thinking while cautioning against assuming that all training activities generate the same academic effects. Liu et al. (2021) likewise linked visual–spatial ability with academic achievement through foundational learning competencies.

Spatial dimensions may not contribute uniformly across domains or student groups. Harris et al. (2021) showed that the roles of spatial orientation, visualization, and mental rotation vary by mathematics content and sometimes by gender. Wang et al. (2021) investigated the relation between early spatial skills and later reading

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and mathematics achievement. In junior high geometry, this literature supports examining visualization, relationships, and orientation separately and testing their association with recorded school performance.

The local study therefore takes academic grades as an observable measure and tests monotonic associations using Spearman rho. This is an appropriate descriptive approach for examining relationships among measured variables but does not establish that spatial reasoning caused better grades. It also does not rule out other influences, such as prior mathematics preparation, instructional opportunities, or students' motivation.

Developmental and Demographic Differences in Spatial Reasoning

Students' opportunities for spatial activity and their familiarity with geometric representations differ across grades and ages. Kurt et al. (2023) investigated spatial reasoning among middle-school students, and Putri (2020) examined junior-high spatial ability and mathematics problem solving. Such literature motivates comparisons among grade and age groups while keeping the distinction between observed group differences and developmental explanations.

Sex-related patterns must also be interpreted carefully. Harris et al. (2021) found that relationships between spatial constructs and mathematics depend partly on the content being assessed. Bartlett and Camba (2023) critically examined the measurement and interpretation of gender differences in spatial ability, arguing against treating observed group patterns as fixed or biologically predetermined. Accordingly, demographic contrasts in this article are interpreted as sample-level patterns that may reflect many educational and experiential influences.

In the present research, students were grouped by age, sex, and grade level for nonparametric comparisons of spatial skills and their applications. These comparisons can identify where differentiated classroom support may be useful, although they cannot demonstrate developmental mechanisms or determine which environmental factors account for observed differences.

Instructional Strategies and Tools for Spatial Learning

Hands-on geometry tasks make otherwise abstract transformations more concrete. Manipulatives, tangrams, solid models, paper folding, and spatial puzzles can support learners' attempts to connect images with geometric properties. Bansil and Yabut (2025) discussed physical-manipulative interventions for Grade 7 spatial reasoning, while Cotabish et al. (2024) considered integrated curriculum and talent development approaches. These studies inform the thesis's emphasis on structured, repeated opportunities to reason with geometric representations.

Technology can extend, but need not replace, these approaches. Guntur and Setyaningrum (2021) examined augmented reality in teaching vectors and spatial problem solving, while Baumgartner et al. (2022) investigated extended reality and spatial reasoning among younger learners. Such technologies may offer interactive opportunities to rotate, compare, and decompose shapes when schools can provide suitable devices, connectivity, and instructional support.

The reviewed research favors instructional combinations rather than a single method: teachers can introduce a physical object, represent it using diagrams or geometry software, invite students to explain a solution with precise spatial language, and conclude with unfamiliar applications. Zhu et al. (2024) stressed purposeful spatial development within authentic STEM experiences. The proposed enhancement program in the thesis follows this orientation through baseline assessment, concrete-to-abstract tasks, collaborative reasoning, and ongoing formative evaluation.

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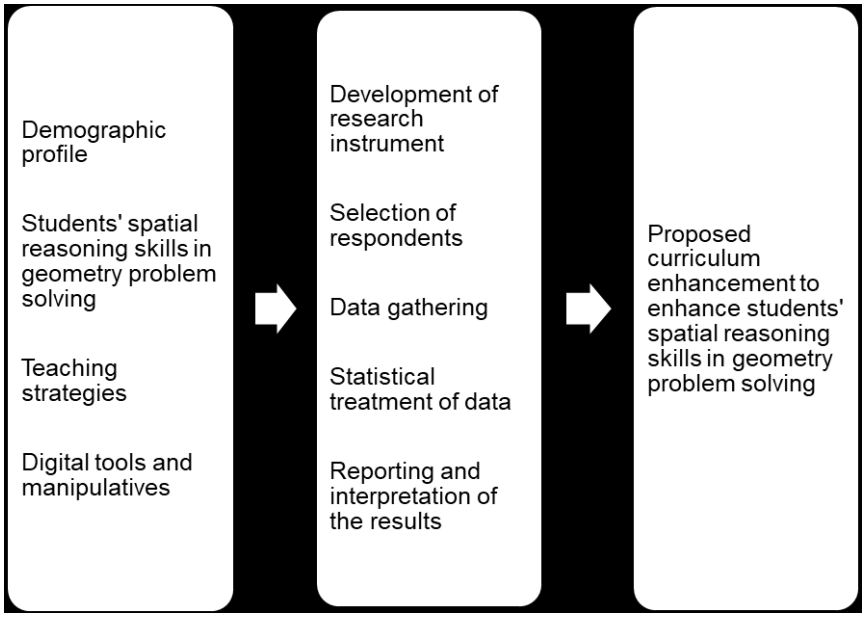


Figure 1. *Research paradigm of the study*

METHODS

Research Design

The study employed a quantitative descriptive-correlational design. The descriptive component documented students' profiles, academic performance, reported spatial skills, application behaviors, and perceptions of instructional strategies. The correlational component examined associations between the three spatial reasoning domains and geometry grades. No experimental intervention was implemented to test causal effects.

Research Locale

Data were obtained from Filomena D. Deramas Integrated School, Salvacion National High School, and Rawis National High School in the Schools Division of Sorsogon City, Philippines. The source methodology identifies these three schools as the participating sites, although an earlier scope paragraph refers to only one; the three-school account is consistent with the reported school-by-school respondent counts.

Participants and Sampling Technique

The stated population was 550 Grades 7–10 students across the three schools (200, 200, and 150, respectively). A total of 300 were selected through simple random sampling, using the Taro Yamane sample-size approach described in the thesis. The respondents comprised 109 from Filomena D. Deramas Integrated School, 102 from Salvacion National High School, and 89 from Rawis National High School. Participation criteria included exposure to geometry instruction and consent; the thesis also described exclusion criteria related to attendance and assessment accessibility. Findings therefore pertain to the sampled learners and should not be treated as population-wide causal estimates.

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Research Instrument

The researcher-made instrument collected age, sex, and grade level; recorded geometry grades; reported levels of spatial visualization, spatial relationships, and spatial orientation; frequency of applied spatial strategies; and appraisals of teaching strategies. Spatial skill levels and application behaviors were rated on four-point scales. Geometry performance was classified using the achievement categories in the school grading records. Expert reviewers, including an education specialist, university research professor, school administrator, and adviser, examined content validity. Cronbach's alpha was identified as the reliability method, but the main manuscript does not provide a consistently reported coefficient for inclusion here.

Data Gathering Procedure

The researcher described submitting permission requests through the Schools Division Office, district supervisor, and principals of the participating schools. After orientation and consent procedures, the structured questionnaire was distributed through an online form and the responses were organized for analysis. Officially recorded geometry ratings supplied the achievement categories. The thesis variously identifies first- and second-grading data in different sections; the correct grading period must be confirmed against the school records before submission.

Data Analysis

Frequencies and percentages summarized demographic and performance categories, while means and standard deviations described scaled responses. Kruskal–Wallis H tests evaluated age- and grade-based differences; Mann–Whitney U tests evaluated sex-based differences. Spearman rank correlations assessed associations between spatial domains and geometry performance, with $p < .001$ reported for the three principal relationships. The numerical values reported below follow the thesis's detailed Chapter 4 tables. The source contains repeated and possibly misassigned labels in part of its group-difference table, which are not silently reinterpreted here.

Ethical Consideration

The study reports administrative permissions, voluntary participation, parental or guardian consent and student assent for minors, confidential data handling, and anonymized reporting. The thesis states compliance with applicable Department of Education procedures. The specific ethics-review approval number was not supplied in a verifiable form in the main manuscript and should be added only if independently documented.

RESULTS AND DISCUSSION

Respondent Profile and Geometry Academic Performance

Among the 300 respondents, 148 (49.3%) were aged 14–15 years, 97 (32.3%) were aged 12–13, and 55 (18.3%) were 16 or older. The sample included 157 males (52.3%) and 143 females (47.7%). Grade 9 accounted for the largest subgroup (104, 34.7%), followed by Grade 7 (86, 28.7%), Grade 10 (83, 27.7%), and Grade 8 (27, 9.0%). These distributions describe the study participants rather than the wider junior-high population.

Table 1. *Respondent demographics and academic performance (n = 300)*

Measure	Category	n	%
Age	12–13 years	97	32.3
	14–15 years	148	49.3
	16 years and above	55	18.3
Sex	Male	157	52.3
	Female	143	47.7
Grade	Grade 7	86	28.7
	Grade 8	27	9.0
	Grade 9	104	34.7
	Grade 10	83	27.7

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Geometry rating	Did Not Meet Expectations	77	25.7
	Fairly Satisfactory	127	42.3
	Satisfactory	86	28.7
	Very Satisfactory	9	3.0
	Outstanding	1	0.3

The largest geometry-achievement group was Fairly Satisfactory (127 students, 42.3%). Another 77 (25.7%) did not meet expectations, whereas 86 (28.7%) were Satisfactory; only 10 (3.3%) were Very Satisfactory or Outstanding. The distribution indicates that many sampled learners had not reached the upper achievement categories, supporting a focus on geometry tasks that require deeper visual interpretation, multi-step reasoning, and spatial explanation.

Levels of Spatial Visualization, Relationships, and Orientation

The reported composite means indicated High spatial visualization (M = 2.62, SD = 0.83) and High spatial relationships (M = 2.62, SD = 0.86). Spatial orientation had a slightly lower but still High mean (M = 2.57, SD = 0.87). Within visualization, interpreting visual patterns (M = 2.76) and mentally manipulating figures (M = 2.75) were among the stronger items, whereas forecasting folding/rotation results (M = 2.40), imagining a geometric shape before drawing (M = 2.48), and reasoning without physical representations (M = 2.49) received weaker ratings.

Table 2. *Summary of reported spatial reasoning levels*

Dimension or selected indicator	Mean	SD	Original rating
Spatial visualization, composite	2.62	0.83	High
Spatial relationships, composite	2.62	0.86	High
Spatial orientation, composite	2.57	0.87	High
Visualization: visual patterns	2.76	0.80	High
Visualization: forecast folding/rotation	2.40	0.78	Moderately Low
Visualization: shapes before drawing	2.48	0.82	Moderately Low
Relationships: multi-step relational problems	2.48	0.84	Moderately Low
Orientation: change viewpoint	2.45	0.91	Moderately Low

For spatial relationships, assessing distance and angle (M = 2.86) and recognizing line relationships (M = 2.84) were rated higher, while applying relational thinking to multi-step geometry problems (M = 2.48) was Moderately Low. In orientation, reading directions (M = 2.76) and identifying grid positions (M = 2.64) were among the stronger reported competencies; modifying viewpoints to solve problems (M = 2.45) and understanding orientation in transformations (M = 2.48) were less developed. This contrast between familiar representations and more demanding transformations is consistent with the distinction Fujita et al. (2020) drew between simple visualization and geometrical reasoning supported by conceptual knowledge.

Students' Application of Spatial Reasoning and Preferred Instructional Strategies

The application of spatial reasoning was rated Often overall (M = 2.68, SD = 0.86). Students reported frequent use of spatial thinking in solving geometry problems (M = 3.06), identifying geometric transformations (M = 2.78), and drawing or sketching problem situations (M = 2.75). Lower scores were observed for identifying tessellation patterns and breaking down forms to find area or volume (both M = 2.47; Sometimes). These are meaningful targets for explicit practice in decomposition, pattern structure, and problem explanation.

Table 3. *Applied spatial reasoning and strategies for teaching geometry*

Domain	Selected behavior or strategy	Mean	Original rating
Application	Spatial thinking to solve geometry problems	3.06	Often
Application	Diagrams/sketches for problem scenarios	2.75	Often
Application	Recognizing tessellations	2.47	Sometimes
Application	Spatial decomposition for area/volume	2.47	Sometimes

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Application	Composite of application items	2.68	Often
Instruction	Manipulatives (blocks, tangrams, solids)	2.93	Agree
Instruction	Spatial puzzles and games	2.90	Agree
Instruction	Dynamic geometry software	2.62	Agree
Instruction	Verbal explanations with spatial terminology	2.46	Disagree
Instruction	Composite instructional-strategy rating	2.71	Agree

Of the instructional strategies surveyed, physical manipulatives (M = 2.93) and spatial puzzles/games (M = 2.90) received the highest ratings. Drawing/sketching (M = 2.77) and use of practical tasks (M = 2.75) also received agreement. Encouraging verbal explanation with spatial terminology was rated lowest (M = 2.46; Disagree), suggesting that instructional planning should connect concrete activities to precise mathematical language. This combination is compatible with research on manipulatives and spatial instruction (Bansil & Yabut, 2025; Cotabish et al., 2024), as well as digital opportunities investigated by Guntur and Setyaningrum (2021) and Baumgartner et al. (2022).

Differences in Spatial Reasoning According to Demographic Profile

The detailed inferential tables showed age-group differences for spatial visualization, H (2) = 218.095, spatial relationships, H (2) = 218.622, and spatial orientation, H (2) = 228.085 (all $p < .001$). For sex-based comparisons, the table reported U = 931.000 for spatial visualization and U = 672.000 for spatial relationships (both $p < .001$). Grade-level test blocks also reported significant differences, including H (3) = 227.928 for the first spatial-visualization block ($p < .001$). The source repeats some category labels in later rows, so the mapping of all three grade/sex test blocks to spatial domains requires verification.

Table 4. *Selected group-difference test results retained from source tables*

Outcome	Grouping	Statistic	p
Spatial visualization	Age	H(2) = 218.095	< .001
Spatial relationships	Age	H(2) = 218.622	< .001
Spatial orientation	Age	H(2) = 228.085	< .001
Spatial visualization	Sex	U = 931.000	< .001
Spatial relationships	Sex	U = 672.000	< .001
Spatial visualization (first block)	Grade	H(3) = 227.928	< .001
Application of spatial reasoning	Age	H(2) = 232.002	< .001
Application of spatial reasoning	Sex	U = 1392.000	< .001
Application of spatial reasoning	Grade	H(3) = 240.256	< .001

The reported application of spatial reasoning also differed by age (H(2) = 232.002), sex (U = 1392.000), and grade (H(3) = 240.256), all $p < .001$. The thesis interprets these differences as generally favoring older, male, and higher-grade students, but it does not provide complete group-specific ranks and direction-of-effect estimates in the summary test tables. Therefore, the defensible inference is that distributions differed across groups; unreported magnitude and rank comparisons should not be assumed. Bartlett and Camba (2023) and Harris et al. (2021) both underscore the importance of careful interpretation of group patterns and the particular spatial constructs being tested.

Relationship Between Spatial Reasoning and Geometry Performance

Spearman's rank correlations were strong and positive for all three domains. Geometry performance correlated with visualization at $\rho = .823$, spatial relationships at $\rho = .833$, and orientation at $\rho = .833$, each reported as statistically significant at $p < .001$. The results indicate that students with higher reported spatial reasoning scores tended also to have better recorded geometry performance within this sample.

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Table 5. *Spearman correlations with geometry academic performance*

Spatial reasoning variable	Spearman ρ	p	Interpretation
Spatial visualization	.823	< .001	Strong positive association
Spatial relationships	.833	< .001	Strong positive association
Spatial orientation	.833	< .001	Strong positive association

These associations accord with related findings that spatial reasoning is relevant to mathematics achievement (Atit et al., 2022; Xu et al., 2025). However, the cross-sectional correlational design and use of questionnaire-based skill ratings limit claims about direction of influence. Spatial reasoning may accompany good mathematical preparation, and both may be associated with unmeasured instructional or socioeconomic factors. An experimental or longitudinal design would be needed to assess whether improving spatial skills causes better geometry grades.

Proposed Spatial Reasoning Enhancement in Geometry

The thesis translated the reported strengths and gaps into a proposed Spatial Reasoning Enhancement in Geometry. Its priorities were strengthening visualization, relationships, and orientation; extending spatial skills to multi-step real-world tasks; differentiating assistance; and monitoring learner progress. Proposed activities included baseline assessment, manipulatives, mental rotation and perspective-taking drills, spatial puzzles, dynamic geometry software such as GeoGebra, inquiry-based investigations, and formative reassessment. These were proposed actions and anticipated outcomes, not implemented or evaluated results of the present study.

Table 6. *Condensed priorities of the proposed curriculum enhancement*

Priority	Illustrative activities	Intended evidence of progress
Core spatial dimensions	Baseline skills check; tangrams, solids, visual pattern and mental-rotation tasks	Progress in spatial visualization, relational and orientation assessments
Complex problem application	Nets of solids; coordinate geometry; tessellations; area/volume decomposition	Accuracy and reasoning in multi-step geometry tasks
Inclusive differentiated support	Small groups, peer activities, adjusted task difficulty, precise spatial vocabulary	Participation and improvement across different readiness levels
Monitoring and refinement	Formative quizzes, teacher reflection, end-of-cycle reassessment	Change in spatial task responses and geometry achievement

Instruction can be sequenced from physical modeling to visualization, sketching, symbolic representation, and verbal justification. Supported by spatial learning research (Hawes et al., 2022; Zhu et al., 2024), this structure offers a feasible basis for school planning, provided its effectiveness is established through a subsequent implementation study.

CONCLUSION

The study found that most sampled students were in the Fairly Satisfactory or lower geometry-performance categories, while their self-reported spatial reasoning levels were generally High across visualization, spatial relationships, and orientation. The weaker abilities were concentrated in demanding tasks: predicting transformations, mentally forming shapes, applying relational reasoning in multi-step problems, and changing viewpoints. Students reported applying spatial skills Often, but had difficulty with tessellations and area/volume decomposition and gave comparatively lower support to verbal spatial explanation. Significant differences were reported by demographic group, and strong positive correlations connected all three spatial domains with geometry performance ($\rho = .823–.833$, $p < .001$). These results support an instructionally relevant association, not proof of causal influence. The proposed Spatial Reasoning Enhancement in Geometry organizes the findings into an educational response focused on conceptual understanding, multimodal practice, inclusion, and periodic assessment.

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Recommendation

Mathematics teachers may deliberately integrate spatial visualization, relationships, and orientation into lessons rather than relying exclusively on routine diagram recognition. Instruction should combine blocks, tangrams, nets, and folding activities with dynamic geometry demonstrations, progressively more complex reasoning tasks, and verbal explanation using precise spatial vocabulary. Greater attention should be devoted to multi-step problems, tessellations, composite area and volume, and perspective changes—areas identified as relatively weak in the study.

School leaders may pilot the proposed Spatial Reasoning Enhancement in Geometry by providing accessible manipulatives and suitable digital resources, protecting time for collaborative lesson planning, and using baseline and follow-up assessments to determine learner needs. Support should be responsive to individual performance rather than based on stereotypes about sex or age. Professional learning for teachers may cover the use of spatial diagnostics and how to move students between concrete, pictorial, and abstract representations.

Future research should confirm the thesis's grading-period descriptions and the mislabeled inferential-table entries against original records; report instrument reliability estimates and complete group rank summaries; and evaluate the proposed program with a comparison group or repeated measures. Additional schools and direct performance-based measures of spatial reasoning would strengthen the applicability and evidential basis of the findings.

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