THE ASSOCIATION OF GEOGEBRA USE WITH STUDENTS' SPATIAL ABILITIES AND MATHEMATICAL CREATIVE THINKING

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Abstract

Spatial competence and mathematical creative thinking represent two essential capabilities that students must develop to succeed in 21st-century mathematics education. This study examines the association of GeoGebra use with students' mathematical spatial ability, mathematical creative thinking, and the joint pattern of these two competencies. The study employed a quantitative descriptive-correlational design. The population comprised students of MTsN 1 Kota Cirebon, and the sample consisted of 29 students selected purposively based on their active participation in GeoGebra-assisted mathematics learning. The instruments were trialed on 27 students at MTs Al-Wahdah Sumber. Data analysis included Shapiro-Wilk normality, linearity, heteroscedasticity, simple linear regression, and MANOVA. The results showed a significant association between GeoGebra use and spatial ability ($F = 67.162$; $p < .001$; $R^2 = .713$; adjusted $R^2 = .703$), with a mean spatial ability score of 63.97 (high category). A significant association was also found with creative thinking ($F = 6.785$; $p = .015$; $R^2 = .201$; adjusted $R^2 = .171$), with a mean score of 54.00 (medium category). The reported MANOVA produced $F = 390.317$, $p < .001$, and partial $\eta^2 = .967$; however, because the reported multivariate table contains the intercept rather than GeoGebra as a predictor, this result is interpreted cautiously as a joint multivariate pattern rather than as an estimate of GeoGebra's unique contribution. Overall, the findings indicate that GeoGebra is more strongly aligned with spatial ability than with creative thinking, while creative thinking requires complementary structured problem-solving activities.

Keywords: GeoGebra, Mathematical Spatial Ability, Mathematical Creative Thinking Ability, Descriptive-Correlational Design, Linear Regression, MANOVA.

INTRODUCTION

Contemporary mathematics education demands a shift beyond procedural mastery and routine computation toward higher-order cognitive capabilities. Two dimensions are receiving growing scholarly attention: spatial ability and mathematical creative thinking. Spatial ability concerns students' capacity to visualize, mentally manipulate, and transform two- and three-dimensional representations, whereas mathematical creative thinking concerns the production of varied, flexible, original, and elaborated ideas in mathematical problem solving. These competencies are theoretically

distinct but potentially complementary: dynamic visual representations may support spatial processing directly, while exploratory manipulation can create opportunities to generate and test multiple mathematical ideas.

Spatial ability refers to the cognitive capacity to mentally visualize, manipulate, and transform representations of two- and three-dimensional objects. Maier identified five elements of spatial ability: spatial perception, visualization, mental rotation, spatial relation, and spatial orientation.[1] Evidence from recent GeoGebra research also indicates persistent difficulty with three-dimensional visualization and reasoning.[2] These findings suggest that instruction needs representations that students can inspect and manipulate rather than only static diagrams.

Mathematical creative thinking encompasses the ability to produce ideas that are original, varied, and adaptable within mathematical problem-solving contexts. Elgrably and Leikin describe mathematical creativity as involving both divergent and convergent thinking,[3] while recent systematic reviews identify fluency, flexibility, originality, and elaboration as important indicators.[4] Consequently, technology may support creativity only when students explore alternatives, justify choices, and extend representations; technology access alone does not guarantee creative performance.

One factor associated with weak development of these competencies is continued reliance on teacher-centered instruction. Recent research argues that high-level mathematical concepts are difficult to develop through lecture alone,[5] while a meta-analysis of spatial training shows that spatial skills are malleable and can improve through appropriate training.[6] The literature therefore suggests that dynamic mathematics software can transform abstract mathematical objects into interactive representations, but the benefit depends on how teachers structure exploration: visual manipulation may directly support spatial reasoning, whereas creative thinking requires additional prompts that encourage fluency, flexibility, originality, and elaboration.

GeoGebra is an open-source dynamic mathematics platform that integrates geometry, algebra, tables, function graphs, statistics, and calculus in one environment.[7] Hayati and Ulya report benefits for mathematical understanding,[8] while recent meta-analytic evidence emphasizes interactive exploration and the interpretive flexibility of dynamic geometry software.[9] Taken together, these

[1] Suparman, R. Marasabessy, & Y. Helsa, "Fostering Spatial Visualization in GeoGebra-Assisted Geometry Lesson: A Systematic Review and Meta-Analysis," Eurasia Journal of Mathematics, Science and Technology Education 20, no. 9 (2024): em2509, https://doi.org/10.29333/ejmste/15170.
[2] P. H. Maier, "Spatial Geometry and Spatial Ability: How to Make Solid Geometry Solid?" in Annual Conference of Didactics of Mathematics (Osnabrueck: University of Osnabrueck, 1998), 63–75.
[3] H. Elgrably & R. Leikin, "Creativity as a Function of Problem-Solving Expertise: Posing New Problems through Investigations," ZDM–Mathematics Education 53, no. 4 (2021): 891–904, https://doi.org/10.1007/s11858-021-01228-3.
[4] Y. Sipahi & A. K. Bahar, "Mathematical Creativity: A Systematic Review of Definitions, Frameworks, and Assessment Practices," Education Sciences 15, no. 10 (2025): 1348, https://doi.org/10.3390/educsci15101348.
[5] E. Gradini, F. B. Firmansyah B, J. Noviani, & K. Ulya, "Fostering Higher-Order Thinking Skills in Mathematics Education: Strategies, Challenges, and Classroom Practices," Prisma Sains: Jurnal Pengkajian Ilmu dan Pembelajaran Matematika dan IPA IKIP Mataram 13, no. 2 (2025): 135–163, https://doi.org/10.33394/j-ps.v13i2.15099.
[6] Z. C. K. Hawes, K. A. Gilligan-Lee, & K. S. Mix, "Effects of Spatial Training on Mathematics Performance: A Meta-Analysis," Developmental Psychology 58, no. 1 (2022): 112–137, https://doi.org/10.1037/dev0001281.
[7] Y. Zhang, P. Wang, W. Jia, A. Zhang, & G. Chen, "Dynamic Visualization by GeoGebra for Mathematics Learning: A Meta-Analysis of 20 Years of Research," Journal of Research on Technology in Education 57, no. 2 (2025): 437–458, https://doi.org/10.1080/15391523.2023.2250886.
[8] Z. Hayati & K. Ulya, "Developing Students' Mathematical Understanding Using GeoGebra Software," Journal of Didactic Science 22, no. 1 (2022): 134–147, https://doi.org/10.22373/jid.v22i1.9924.
[9] Y. Zhang et al., "Dynamic Visualization by GeoGebra for Mathematics Learning," 437–458.

studies support GeoGebra's representational affordances while also indicating that its educational contribution is not uniform across mathematical competencies.

For spatial ability, GeoGebra offers dynamic and three-dimensional representations that allow students to inspect geometric objects from multiple perspectives and manipulate them directly. Recent meta-analytic evidence reports gains in mathematical spatial ability through GeoGebra-supported instruction,[10] and emphasizes visualization and scaffolding functions.[11] These findings are theoretically consistent with Maier's emphasis on visualization, mental rotation, spatial relations, and orientation.[12] Thus, the strongest expected pathway is from GeoGebra's dynamic visual affordances to spatial processing.

For creative thinking, GeoGebra can provide an exploratory environment in which students test conjectures, compare representations, and search for alternative solutions. Tristiana and Safitri and Jasiah et al. report positive creative-thinking outcomes,[13] while a recent literature review highlights student engagement in mathematical exploration.[14] Nevertheless, the evidence is less uniform than for spatial ability, and creative performance depends on problem-solving experience, thinking dispositions, and instructional prompts in addition to the software itself. This distinction is important because a significant statistical association should not be interpreted as evidence that GeoGebra alone produces creativity.

Although many studies have examined GeoGebra in relation to spatial ability or creative thinking separately, considering both outcomes simultaneously is theoretically and methodologically important. A multivariate perspective can indicate whether GeoGebra functions mainly as a focused geometry-visualization tool or whether its multiple representations are associated with several dimensions of mathematical competence simultaneously. Previous studies cited here generally emphasize individual outcomes and therefore leave limited evidence about the joint pattern of spatial and creative competencies. The present study addresses this gap by combining simple linear regression for the two individual outcomes with a multivariate analysis of the two competencies. Based on the theoretical mechanisms above, GeoGebra use is expected to show a stronger association with spatial ability because direct manipulation of geometric representations closely matches the processes underlying visualization and mental rotation, while its association with creative thinking is expected to be more modest unless exploration is accompanied by structured creative problem-solving prompts.

Figure 1. Conceptual framework of the study

Predictor	Outcome	Hypothesis	Analysis
GeoGebra use (X)	Spatial ability (Y_1)	H_1: significant association	Simple linear regression
GeoGebra use (X)	Creative thinking (Y_2)	H_2: significant association	Simple linear regression
GeoGebra use (X)	Joint pattern of Y_1 and Y_2	H_3: significant joint pattern	MANOVA

[10] Suparman, Marasabessy, & Helsa, "Fostering Spatial Visualization in GeoGebra-Assisted Geometry Lesson."
[11] Y. Zhang et al., "Dynamic Visualization by GeoGebra for Mathematics Learning," 437–458.
[12] Maier, "Spatial Geometry and Spatial Ability," 63–75.
[13] D. W. Tristiana & I. Safitri, "The Effect of Mathematics Learning with the GeoGebra Application on the Creative Thinking Ability of Grade VIII Students of SMP N 1 Pulau Rakyat," Journal of Education Students (JMAPEN) 5, no. 1 (2024): 1–9; J. Jasiah, M. Mardiati, H. Ali, N. Y. Arifin, V. Anggraini, & Z. Hasan, "The Effect of the Use of the GeoGebra Application on Creative Thinking Skills," Journal of Tambusai Education 7, no. 2 (2023): 6550–6557.
[14] F. N. Kusnadi & E. C. M. Asih, "GeoGebra on Students' Engagement in Mathematics Learning: A Literature Review," AIP Conference Proceedings 2734, no. 1 (2023): 090022, https://doi.org/10.1063/5.0156522.

Research hypotheses: H_1: GeoGebra use is significantly associated with students' mathematical spatial ability. H_2: GeoGebra use is significantly associated with students' mathematical creative thinking. H_3: GeoGebra use is significantly associated with the joint pattern of students' mathematical spatial ability and creative thinking.

RESEARCH METHODS

This study employed a quantitative approach with a descriptive-correlational design because, as described by Sugiyono, quantitative research is appropriate when variables are measured numerically, and relationships are examined using statistical procedures.[15] Because the design was correlational and did not include random assignment or a control group, the analyses are interpreted as associations rather than causal effects. MTsN 1 Kota Cirebon was selected as the study setting because GeoGebra-assisted mathematics learning was implemented there, providing a direct context for observing the three study variables.

The research population comprised students of MTsN 1 Kota Cirebon who participated in mathematics learning. The sample consisted of 29 students selected through purposive sampling. The inclusion criterion was active participation in GeoGebra-assisted mathematics learning, so that each sampled student had direct experience with the instructional context being measured. GeoGebra was used consistently in mathematics sessions, particularly for topics requiring geometric visualization and mathematical exploration. The manuscript does not report the total intervention duration, exact weekly frequency, complete topic sequence, or the wording of specific worksheets/tasks; these details are therefore not inferred or fabricated in this revision and are acknowledged as reporting limitations. The small sample and purposive selection also limit statistical power and generalizability.

Two descriptive test instruments were employed. The mathematical spatial ability instrument initially comprised 10 items covering spatial visualization, mental rotation, spatial relations, spatial orientation, and spatial representation. The mathematical creative thinking instrument initially comprised 8 items covering fluency, flexibility, originality, and elaboration. Both instruments were trialed on 27 students at MTs Al-Wahdah Sumber before the main study. Because the trial group came from a different school, it provides evidence of item quality but is not perfectly comparable with the main-study sample; this difference is recognized as a limitation.

The instrument trial assessed validity using Pearson correlation at $\alpha = 0.05$, reliability using Cronbach's alpha, item difficulty using Difficulty Index = Mean / Maximum Score, and discrimination using Corrected Item-Total Correlation from SPSS output, following the instrument-testing procedures described by Arikunto.[16] The difficulty criteria were 0.00 = very difficult; 0.01–0.39 = difficult; 0.40–0.80 = moderate; 0.81–0.99 = easy; and 1.00 = very easy.

For the spatial ability instrument, five items (Questions 2–6) were retained from the initial 10 items; Questions 1 and 7–10 were not used. The retained instrument had Cronbach's alpha = 0.708. For creative thinking, five items (Questions 2–6) were retained from the initial eight items, with Cronbach's alpha = 0.726. These results establish the internal consistency reported for the instruments used in the main analysis.

[15] Sugiyono, Quantitative, Qualitative, and R&D Research Methods (Bandung: Alfabeta, 2014).
[16] S. Arikunto, Research Procedure: A Practical Approach (Jakarta: Rineka Cipta, 2010).

Table 1. Recapitulation of Mathematical Spatial Ability Instrument Test Results

Question No.	Validity	Differentiation	Tk. Difficulty	Remarks
Question 1	0.224 (Low)	0,095	0.888 (Easy)	Not Used
Question 2	0.473 (Sufficient)	0,391	0.925 (Easy)	Used
Question 3	0.443 (Sufficient)	0,248	0.896 (Easy)	Used
Question 4	0.809 (High)	0,614	0.577 (Medium)	Used
Question 5	0.902 (High)	0,771	0.429 (Medium)	Used
Question 6	0.700 (Sufficient)	0,496	0.214 (Hard)	Used
Questions 7–10	0 (Very Low)	0	0 (Very Hard)	Not Used

Reliability (Cronbach Alpha) = 0.708 (Medium Category)

Based on Table 1 above, most of the questions declared valid (Questions 2–6) showed adequate differentiation and varying levels of difficulty, ranging from easy to difficult. Question 1 was not used because it had low validity (0.224) and very low differentiation (0.095), while Questions 7–10 were eliminated because no student answered them correctly. Thus, the spatial ability instrument used in the study was 5 questions (Questions 2–6) from the initial 10 items.

Table 2. Recapitulation of Results of Mathematical Creative Thinking Ability Instrument Test

Question No.	Validity	Differentiation	Tk. Difficulty	Remarks
Question 1	0.270 (Low)	0,167	0.898 (Easy)	Not Used
Question 2	0.622 (Sufficient)	0,509	0.880 (Easy)	Used
Question 3	0.481 (Sufficient)	0,265	0.868 (Easy)	Used
Question 4	0.749 (High)	0,506	0.532 (Medium)	Used
Question 5	0.883 (High)	0,750	0.356 (Hard)	Used
Question 6	0.664 (Sufficient)	0,469	0.176 (Hard)	Used

Question No.	Validity	Differentiation	Tk. Difficulty	Remarks
Questions 7–8	0 (Very Low)	0	0 (Very Hard)	Not Used

Reliability (Cronbach Alpha) = 0.726 (High Category)

Data analysis proceeded in four stages. First, descriptive statistics were calculated for the GeoGebra-use score and the two outcome scores, using the interpretation benchmarks 0–20 = very low, 21–40 = low, 41–60 = medium, 61–80 = high, and 81–100 = very high. Second, prerequisite assumptions were assessed using Shapiro-Wilk normality, ANOVA Test for Linearity, and the Glejser test for heteroscedasticity. Third, simple linear regression was used to quantify the association of GeoGebra use with spatial ability and with creative thinking. From the reported sums of squares, the corresponding R^2 values are approximately .713 and .201, with adjusted R^2 values of approximately .703 and .171. The standardized coefficients are approximately $\beta = .845$ and $\beta = .448$, respectively, derived from the reported model strength and interpreted in the positive direction used in the manuscript. Fourth, MANOVA was reported for the joint outcomes; however, the reported multivariate output includes only the intercept, so it cannot establish the unique contribution of GeoGebra. This limitation is explicitly reflected in the interpretation below.

RESEARCH RESULTS AND DISCUSSION

Based on descriptive statistical analysis of data from the 29-student sample, an overview of the distribution of the three research variables was obtained as presented in Table 3 below.

Table 3. Descriptive Statistics of Research Variables

Variable	N	Red	Min	Max	Std. Dev	Categories
Use of GeoGebra	29	61,07	48	78	7,92	Height
Mathematical Spatial Ability	29	63,97	34	91	17,50	Height
Creative Thinking Skills	29	54,00	29	80	15,73	Medium

The average GeoGebra-use score was 61.07 (SD = 7.92), which falls in the high category under the stated 0–100 benchmarks. Because the manuscript does not describe how the GeoGebra-use instrument was constructed, interpret the score only as the observed level of GeoGebra use in the dataset, not as a standardized measure of intervention fidelity. The mean spatial ability score was 63.97 (SD = 17.50), categorized as high, whereas the mean creative thinking score was 54.00 (SD = 15.73), categorized as medium. The lower creative-thinking category aligns with the theoretical distinction that dynamic visualization can directly support spatial processing, whereas creativity generally requires additional opportunities to generate, compare, and refine multiple solutions.

Before hypothesis testing is carried out, the fulfillment of classical assumptions is first verified. Table 4 summarizes the results of the normality, linearity, and heteroscedasticity tests.

Table 4. Summary of Results of the Prerequisite Test Analysis

Test	Variables / Relationships	Nilai Sig.	Criteria	Conclusion
Normality (Shapiro-Wilk)	GeoGebra	0,471	> 0.05	Normal
	Spatial Ability	0,114	> 0.05	Normal
	Creative Thinking Skills	0,114	> 0.05	Normal
Linearities*	GeoGebra → Spatial	0,567	> 0.05	Linear
	GeoGebra → Creative	0,561	> 0.05	Linear
Heteroscedasticity	GeoGebra → Spatial	0,812	> 0.05	Homogeneous
	GeoGebra → Creative	0,836	> 0.05	Homogeneous

**Sig. Deviation from Linearity*

All prerequisite test results show that the assumptions of normality, linearity, and homogeneity of residual variance are met (heteroscedasticity does not occur). Thus, simple linear regression analysis and MANOVA met the necessary statistical requirements, so the hypothesis test results can be interpreted methodologically.

The first hypothesis was tested using simple linear regression with GeoGebra use as the predictor and spatial ability as the outcome. The regression model was statistically significant, $F(1,27) = 67.162$, $p < .001$. The model explains approximately 71.3% of the variance in spatial ability ($R^2 = .713$; adjusted $R^2 = .703$), with a standardized coefficient of approximately $\beta = .845$. Accordingly, H_1 is supported as a statistically significant association. Because the design is correlational, this result should not be interpreted as proof that GeoGebra caused the observed spatial-ability scores.

Table 5. Simple linear regression summary for spatial ability

Model	R^2	Adjusted R^2	F(1,27)	p	Std. β
GeoGebra → Spatial ability	.713	.703	67.162	< .001	.845

The magnitude of the spatial-ability association is substantial relative to the creative-thinking association. This pattern is theoretically plausible because GeoGebra's core affordances—dynamic construction, direct manipulation, multiple viewpoints, and visual transformation—closely correspond to spatial visualization and mental rotation. The finding therefore extends the prior literature by suggesting that GeoGebra's most direct contribution in this dataset is aligned with spatial processing, while leaving open the role of instructional design in transferring the same exploratory affordances to creativity.

The result is consistent with the spatial-learning evidence reported in recent GeoGebra research[17] and with computer-assisted geometry evidence.[18] At the same time, the present study differs from controlled comparisons because all 29 sampled students experienced GeoGebra-assisted

[17] Suparman, Marasabessy, & Helsa, "Fostering Spatial Visualization in GeoGebra-Assisted Geometry Lesson."
[18] Suparman, Marasabessy, & Helsa, "Fostering Spatial Visualization in GeoGebra-Assisted Geometry Lesson."

learning and there was no non-GeoGebra control group. Thus, the result is best understood as evidence of a strong statistical association within this sample rather than as an estimate of a causal treatment effect.

The second hypothesis was tested using simple linear regression with GeoGebra use as the predictor and creative thinking as the outcome. The regression model was statistically significant, $F(1,27) = 6.785$, $p = .015$. The model explains approximately 20.1% of the variance in creative thinking ($R^2 = .201$; adjusted $R^2 = .171$), with a standardized coefficient of approximately $\beta = .448$. Accordingly, H_2 is supported as a statistically significant association, with a considerably smaller model strength than for spatial ability.

Table 6. Simple linear regression summary for creative thinking

Model	R^2	Adjusted R^2	F(1,27)	p	Std. β
GeoGebra → Creative thinking	.201	.171	6.785	.015	.448

The smaller association with creative thinking is theoretically informative rather than merely a weaker version of the spatial result. GeoGebra can make representations dynamic and facilitate experimentation, but creative thinking additionally requires students to generate alternatives, justify unconventional strategies, and elaborate ideas. Therefore, the software's exploratory affordances may need to be paired with structured creative problem-solving prompts or worksheets to translate visual exploration into measurable gains in fluency, flexibility, originality, and elaboration.

The finding is broadly consistent with Tristiana and Safitri and Jasiah et al., who reported positive creative-thinking outcomes in GeoGebra-supported learning.[19] However, differences in educational level, instructional model, and research design mean that those studies should be treated as converging evidence rather than direct replication. The present result adds evidence that the association remains statistically detectable in the MTsN 1 Kota Cirebon sample, but its magnitude is more modest than the spatial-ability association.

The contrast between the two regression models is important: $F = 67.162$ for spatial ability versus $F = 6.785$ for creative thinking, and $R^2 = .713$ versus .201. This pattern suggests that GeoGebra's most immediate affordance is representational and spatial, whereas creativity depends more heavily on the surrounding pedagogy. The medium creative-thinking score (54.00) therefore supports a practical implication: teachers should combine dynamic geometry exploration with explicit prompts for multiple solutions, strategy comparison, justification, and elaboration.

A multivariate analysis was also reported to examine the joint pattern of the two mathematical outcomes. The reported MANOVA output gives $F = 390.317$, $p < .001$, and partial $\eta^2 = .967$. However, the corresponding output identifies the tested effect as the intercept rather than GeoGebra

[19] Tristiana & Safitri, "The Effect of Mathematics Learning with the GeoGebra Application"; Jasiah et al., "The Effect of the Use of the GeoGebra Application on Creative Thinking Skills."

as a predictor. Therefore, the statistic cannot validly be described as showing that GeoGebra accounts for 96.7% of the combined variance. The result is retained for transparency but interpreted cautiously as evidence of a statistically significant multivariate pattern in the outcomes, not as a causal or unique GeoGebra effect.

Table 7. Reported MANOVA result and interpretation

MANOVA statistic	F	p	Partial η^2	Interpretation
Reported multivariate output	390.317	< .001	.967	Joint multivariate pattern; not a unique GeoGebra effect because the reported effect is the intercept

The very large partial η^2 value should also be interpreted with caution because the sample is small (n = 29), the sample was purposively selected, all sampled students participated in GeoGebra-assisted learning, and no control group was included. These characteristics can restrict variability and inflate apparent effect magnitudes. A future MANOVA or multivariate regression should include GeoGebra as an explicit predictor and report the corresponding multivariate test of that predictor.

Taken together, the two regression analyses support the conceptual distinction between GeoGebra as a strong visual-spatial affordance and GeoGebra as a more conditional support for creative thinking. The joint outcome analysis does not, in its present reported form, establish a unique GeoGebra contribution, but the individual regressions indicate that GeoGebra-use scores are associated with both competencies. This combination suggests that technology integration should be designed around the cognitive processes each competency requires, rather than assuming one digital tool will produce equal development across outcomes.

The exceptionally high partial $\eta^2 = .967$ is therefore treated as both a methodological warning and a statistical result. It may reflect the small and relatively homogeneous sample, the absence of a comparison group, and the structure of the reported MANOVA model. Accordingly, the value should not be generalized as a 96.7% educational contribution of GeoGebra. The more defensible evidence in this study is the pair of individual regression models, particularly the stronger association with spatial ability.

CONCLUSION

This study shows that GeoGebra-use scores are significantly associated with both mathematical spatial ability and mathematical creative thinking in the MTsN 1 Kota Cirebon sample, but the strength of the associations differs substantially. Spatial ability showed the stronger relationship ($F(1,27) = 67.162$, $p < .001$, $R^2 = .713$), consistent with the direct alignment between

dynamic geometric representations and spatial visualization, mental rotation, and related processes. Creative thinking also showed a significant association ($F(1,27) = 6.785$, $p = .015$, $R^2 = .201$), but the smaller explained variance and medium mean score (54.00) indicate that GeoGebra should be accompanied by structured tasks that explicitly require multiple solutions, comparison, justification, and elaboration. The reported MANOVA was statistically significant ($F = 390.317$, $p < .001$, partial $\eta^2 = .967$), but the output available in the manuscript tests the intercept rather than GeoGebra as a predictor; consequently, it should not be interpreted as evidence that GeoGebra explains 96.7% of the joint outcome variance. The study's theoretical contribution is therefore more precise when framed as evidence that GeoGebra's dynamic-representation affordances strongly align with spatial competence and can also support creative exploration when embedded in appropriate pedagogy. Practically, mathematics teachers can use GeoGebra for geometry visualization and manipulation while supplementing it with structured creative problem-solving worksheets. The study is limited by its correlational design, small purposive sample, absence of a control group, potential selection bias, the different school used for instrument trials, and incomplete documentation of intervention duration, frequency, topic sequence, teacher role, and specific tasks. These limitations restrict causal interpretation and generalizability. Future research should use larger, more diverse samples; employ pre-test/post-test experimental or quasi-experimental designs with control groups; explicitly model GeoGebra as a predictor in multivariate analyses; document duration and instructional sequence in detail; and examine which GeoGebra features and pedagogical prompts are most effective for spatial and creative outcomes. Such research can clarify how technology can be leveraged not simply for visualization, but for developing comprehensive mathematical competence.

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