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Improving Spatial Ability Using GeoGebra and Kahoot-Assisted Guided Discovery Learning Models

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Abstract: At the school level, the material presented in mathematics learning includes various types, such as geometry, statistics, algebra, and arithmetic. Among these branches, geometry particularly requires strong spatial abilities, as students are expected to visualize, interpret, and mentally manipulate objects. Students' spatial abilities remain relatively low. However, a literature review on spatial ability revealed a multiplicity of spatial taxonomies and analytical frameworks that lack convergence, presenting a confusing terrain for researchers to navigate. Spatial ability refers to an individual's capacity to form, transform, represent, and recall non-verbal information that is visual or symbolic in nature. However, in practice, many students still demonstrate relatively low spatial skills, which can hinder their understanding of mathematical concepts and problem-solving processes. Therefore, innovative learning strategies and technological support are needed to help students improve these abilities. One alternative is to integrate interactive learning media, such as GeoGebra 3D Calculator and Kahoot, into mathematics instruction. This study aimed to analyze improvements in students' spatial abilities through the implementation of the Guided Discovery Learning model, assisted by GeoGebra and Kahoot. The research employed a quantitative approach with a quasi-experimental design. The findings revealed that implementing the Guided Discovery Learning model, supported by GeoGebra and Kahoot, significantly improved students' spatial abilities. The use of GeoGebra 3D Calculator enabled students to visualize three-dimensional mathematical objects more clearly, while Kahoot increased students' engagement and motivation during the learning process through interactive activities. In addition, the guided discovery approach encouraged students to actively explore concepts, construct their own understanding, and develop critical thinking skills. Overall, the integration of guided discovery learning with interactive technology media positively affected not only students' cognitive achievement but also their affective aspects, such as confidence, motivation, and reduced mathematics anxiety.

Keywords: geogebra, guided discovery learning, spatial ability.

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INTRODUCTION

Mathematics is a method of thinking used to solve problems in industry, government, and science (English, 2023). At the school level, the material presented in mathematics education is varied, including geometry, statistics, algebra, and arithmetic (Oliveira et al., 2022). The presentation of the learning material shows that spatial skills are necessary in mathematics (Schenck et al., 2024). This is because mathematics learning activities depend on the individual's ability to imagine and understand the material (Yilmaz & Yilmaz, 2017). In addition, learning mathematics requires the ability to think visually and to manipulate several objects in space (Harris, 2023).

Spatial skills are individual skills for forming, changing, representing, and remembering non-verbal information with a visual or symbolic nature (Tiwari et al., 2024). Spatial ability concerns how individuals perceive relationships among multiple objects through mental imagery (Batubara, 2019). Based on further analysis, spatial ability comprises two primary dimensions: spatial visualization and spatial orientation (Gittinger & Wiesche, 2024). Therefore, this study employed an instrument that measured both dimensions separately to identify the intervention's influence on each aspect of spatial ability (Xie et al., 2020). Spatial visualization refers to the ability to mentally reverse, manipulate, and rotate 2D and 3D shapes (Cui & Guo, 2022). Furthermore, spatial orientation is the ability to understand how an object is arranged in space and to recognize it even if its position or perspective changes (Chikiwa.

One of the competencies that must be developed in mathematics learning is spatial ability, as identified by NCTM (Di & Zheng, 2022). Research by Zulhafendi & Yarman (2026) found that students' learning outcomes improved compared with conventional learning when Cabri 3D was used as a visual media-assisted geometry learning tool. This can minimize difficulties in understanding mathematical material (Yang et al., 2025). The use of visual media also shows an increase in spatial skills, enabling students to analyze Geometry material more thoroughly (Changwong et al., 2021).

Then, the research by Hattie & Donoghue (2019) shows that the extent of explanation of spatial abilities to students remains relatively low. The results of the study explained that the spatial ability of students was at a low level, which had a percentage score of 29.2%, at the medium level related to spatial ability had a percentage score of 58.3%, and at a high level related to spatial ability had a percentage score of 12.5% (Papakostas et al., 2021). The results of interviews conducted at the junior high school level show difficulty in imagining an object after reflection or rotation on the building material. Furthermore, students have difficulty understanding spatial concepts as a whole.

Research by Schenck (2022) reported the main findings of the study, namely that high levels of spatial anxiety are associated with low mathematical scores and spatial ability. The next finding is that success in certain types of tasks is influenced by several factors from the sub-category of spatial ability. The final finding of the study is that there is a varied correlation between students' mathematical and spatial abilities. Based on the study's results, it is clear that students' spatial abilities are complex.

The integration of technology in mathematics learning requires not only the use of digital tools, but also an appropriate pedagogical approach that aligns technology, learning objectives, and subject content NCTM (Li & Li, 2024). In this context, the Technological Pedagogical Content Knowledge (TPACK) framework provides a theoretical foundation for understanding how technology, pedagogy, and content knowledge can be effectively integrated into classroom learning (Papakostas et al., 2021). According to the TPACK framework, effective technology-based learning occurs when teachers combine pedagogical strategies, technological tools, and subject-matter knowledge simultaneously to support meaningful learning experiences (Sierra et al., 2023).

In this study, the Guided Discovery Learning (GDL) model represents the pedagogical component that encourages students to actively explore, investigate, and construct mathematical concepts independently through guided activities. GeoGebra 3D Calculator serves as the technological and content-support component, providing dynamic visualization of geometric objects and spatial relationships. Through GeoGebra, students can manipulate, rotate, and observe two-dimensional and three-dimensional objects interactively, making abstract geometric concepts more concrete and easier to understand (Zhang et al., 2025). Meanwhile, Kahoot serves as a technological tool for evaluation and learning engagement by providing interactive quizzes, immediate feedback, and competitive learning activities that increase students' participation and motivation during mathematics learning.

The synergy among Guided Discovery Learning, GeoGebra, and Kahoot is theoretically relevant to improving spatial ability because each component supports distinct aspects of students' cognitive processes. Guided Discovery Learning promotes active conceptual construction, GeoGebra strengthens spatial visualization and spatial orientation through dynamic representations, and Kahoot reinforces understanding through interactive assessment and immediate feedback. Therefore, the combination of these three elements reflects the practical implementation of the TPACK framework in mathematics learning, particularly in geometry instruction involving spatial reasoning.

In addition, this study is also supported by Cognitive Load Theory (Di & Zheng, 2022), which explains that learning effectiveness can increase when instructional design minimizes unnecessary cognitive load and helps students focus on essential information processing. Geometry learning often requires students to mentally manipulate abstract objects, which may create excessive cognitive load, especially for students with low spatial ability. The use of GeoGebra helps reduce extraneous cognitive load by transforming abstract geometric concepts into dynamic visual representations that are easier to process cognitively. At the same time, Guided Discovery Learning systematically structures students' exploration activities, while Kahoot provides immediate feedback and engaging reinforcement activities that help maintain students' attention and motivation during learning. Consequently, integrating these components is expected to create a more effective and cognitively supportive learning environment for the development of students' spatial abilities.

To overcome learning problems, especially in mathematics, learning media or props can be used as solutions. Along with the times, learning media have also undergone developments that present sound or images, whereas previously they were only presented in the form of writing and text (Gourdeau, 2015). Furthermore, the use of learning media can be integrated with ICT (Information and Communication Technology) development (Kalogiannakis et al., 2021). After the invention of computers, the field of ICT has developed rapidly, as evidenced by the emergence of various tools such as smartphones, Infocus, and so on (Lapenok et al., 2019).

The lack of spatial ability among students can be addressed using GeoGebra 3D Calculator software (Pishtari et al., 2023). The software can be accessed via a smartphone or Android device. Based on the dimensional analysis conducted in this study, spatial ability consisted of two main dimensions, namely spatial visualization and spatial orientation. The findings revealed that both dimensions improved after the learning intervention, although the increase in spatial visualization was more prominent. This indicates that integrating GeoGebra and Kahoot into the Guided Discovery Learning model was particularly effective in supporting students' ability to dynamically manipulate and visualize geometric objects while also improving their understanding of spatial positions and perspectives.

Based on the TPACK framework and Cognitive Load Theory, implementing technology-assisted mathematics learning requires a learning model that simultaneously aligns pedagogical approaches, technological tools, and mathematical content knowledge. Therefore, this study integrates Guided Discovery Learning, GeoGebra 3D Calculator, and Kahoot as complementary components to support the development of students' spatial abilities in geometry learning. In this study, the GeoGebra

3D Calculator application was integrated with the Guided Discovery Learning model to support the improvement of students' spatial abilities, particularly in three-dimensional geometry. Guided Discovery Learning encourages students to actively explore, analyze, and construct mathematical concepts independently, while GeoGebra helps them visualize abstract geometric objects more concretely and interactively. In addition, Kahoot was incorporated as an interactive evaluation and engagement tool to increase students' motivation, participation, and enthusiasm during the learning process. Previous studies generally examined the use of Guided Discovery Learning and GeoGebra separately, or focused solely on interactive learning media, without integrating pedagogical, technological, and evaluative components simultaneously. Furthermore, few studies have examined the integration of Guided Discovery Learning, GeoGebra 3D Calculator, and Kahoot within the TPACK framework and from a Cognitive Load Theory perspective to improve students' spatial abilities. Therefore, the novelty of this study lies not only in the combination of these three instructional components but also in the theoretical integration of pedagogy, technology, content knowledge, and cognitive support in mathematics learning. However, studies that integrate Guided Discovery Learning, GeoGebra 3D Calculator, and Kahoot simultaneously to improve students' spatial abilities remain limited. Therefore, the novelty of this research lies in combining these three elements in mathematics learning, which is expected not only to improve students' spatial literacy and conceptual understanding of geometry but also to create a more interactive, engaging, and meaningful learning environment, especially when learning flat-sided three-dimensional shapes. Thus, the application of the GeoGebra-assisted Discovery Learning model (Velázquez & Méndez, 2021) is hoped to facilitate students' spatial literacy skills in understanding geometry concepts in depth, especially in the material on building flat-sided spaces.

In the above study, the author titled it "Improving Spatial Ability Using GeoGebra and Kahoot-Assisted Guided Discovery Learning Models". The purpose of the study was to analyze improvements in spatial abilities using the guided discovery learning model, assisted by GeoGebra and Kahoot. In addition, this study seeks to answer the following research question: "Does the implementation of the Guided Discovery Learning model assisted by GeoGebra and Kahoot significantly improve students' spatial abilities in mathematics learning?" Accordingly, the hypothesis proposed in this study is that students who learn through the Guided Discovery Learning model assisted by GeoGebra and Kahoot demonstrate better improvement in spatial abilities compared to students who experience conventional learning methods.

■ METHOD

The research method used in this study was quantitative, employing a quasi-experimental design. The study was conducted on two groups: an experimental group and a control group. The experimental group was taught using the guided discovery learning model, with support from GeoGebra and Kahoot. In contrast, the control group was taught using the same model without these tools.

Participants

The population of this study consisted of all eighth-grade students of junior high schools in Bandung City during the 2025–2026 academic year. The sample was selected using purposive sampling, which involves selecting participants based on specific criteria relevant to the study's objectives. The sample consisted of two eighth-grade classes, one assigned as the experimental group and the other as the control group.

Purposive sampling was employed because the study required classes with relatively comparable academic characteristics and learning conditions. The selected classes met several criteria: (1) both classes had relatively similar mathematics achievement levels based on previous semester scores, (2) the students had not previously experienced Guided Discovery Learning assisted by GeoGebra and Kahoot, and (3) both classes were taught by the same mathematics teacher to maintain consistency in the learning process and reduce potential external variables that might influence the research results. The experimental group was taught using the Guided Discovery Learning model, with assistance from GeoGebra 3D Calculator and Kahoot. In contrast, the control group received instruction using the same Guided Discovery Learning model without integrating technology-based tools. This design was intended to examine the effect of technology integration within the Guided Discovery Learning framework on students' spatial abilities.

Research Design and Procedures

This study employed a quantitative approach with a quasi-experimental pretest–posttest control group design. The study involved two groups: an experimental group and a control group. The experimental group received instruction through the Guided Discovery Learning model, assisted by GeoGebra 3D Calculator and Kahoot. In contrast, the control group was taught using the Guided Discovery Learning model without integrating GeoGebra and Kahoot. The research was conducted over three weeks, comprising six meetings, each lasting approximately 80 minutes. The research procedures were divided into three stages: preparation, implementation, and evaluation. During the preparation stage, the researchers conducted a preliminary study, developed instructional materials, prepared lesson plans, and designed learning activities based on the Guided Discovery Learning model. The experimental class learning activities were supported by GeoGebra 3D Calculator and Kahoot, whereas the control class used printed learning materials and classroom discussions without technology integration. The research instruments were then validated through expert judgment and pilot testing before being implemented in the classroom. In the implementation stage, both groups were first administered a pretest to measure students' initial spatial abilities. The experimental class participated in discovery-based learning activities using GeoGebra 3D Calculator to visualize and manipulate three-dimensional objects interactively. Students worked collaboratively in small groups to explore geometry concepts, analyze object rotations, identify relationships between nets and solid figures, and observe objects from different perspectives. The teacher acted as a facilitator, guiding discussions and encouraging students to draw conclusions independently. At the end of each lesson, Kahoot was used as an interactive evaluation medium to reinforce students' understanding and increase classroom engagement through quizzes and competitive activities. Meanwhile, the control group participated in Guided Discovery Learning activities using non-digital instructional media. Students explored the same geometry concepts through teacher-guided discussions, textbook illustrations, worksheets, and manual drawings of three-dimensional objects. Similar to the experimental class, students worked collaboratively in groups and were encouraged to discover mathematical relationships independently; however, no digital visualization tools or game-based assessment platforms were used in the learning process. In the evaluation stage, both groups were given a posttest to measure students' improvement in spatial ability after the intervention. The collected data were subsequently analyzed statistically to determine the effectiveness of the implemented learning model.

Instruments

The instruments used in this study consisted of instructional materials and a spatial ability test. The instructional materials included lesson plans, teaching modules, student worksheets, and learning media designed based on the Guided Discovery Learning model, assisted by GeoGebra 3D Calculator and Kahoot. These materials were developed by the researchers in accordance with the independent curriculum and were validated by experts in mathematics education prior to classroom implementation. The main research instrument was a spatial ability test administered as a pretest and a posttest. The test was developed and adapted from previous studies on spatial ability and geometry learning by Chikiwa & Schäfer (2021) and from NCTM standards related to spatial reasoning in mathematics learning. The instrument was designed to measure three dimensions of spatial ability, namely: (1) spatial visualization, referring to the ability to mentally manipulate geometric objects; (2) spatial orientation, referring to the ability to recognize object positions from different viewpoints; and (3) mental rotation, referring to the ability to mentally rotate two-dimensional and three-dimensional objects. The test consisted of ten essay and visualization-based items related to flat-sided three-dimensional geometry. Each item was designed to measure one or more indicators of spatial ability. For example, in the spatial visualization dimension, students were asked to determine the resulting shape after a cube net was folded into a three-dimensional object. In the spatial orientation dimension, students identified how a geometric object appears from different perspectives. Meanwhile, in the mental rotation dimension, students were required to predict the position of an object after undergoing a certain degree of rotation. One sample item used in the instrument was: "*Observe the following cube net. Determine which sides will be opposite each other after the net is folded into a cube*." Another item asked students to "*identify the front view, side view, and top view of a three-dimensional object after being rotated 90° clockwise*." These items were intended to assess students' ability to visualize, manipulate, and mentally interpret spatial relationships. To establish content validity, the instrument was reviewed by two mathematics education lecturers and one mathematics teacher. The validation process focused on the relevance of the items to the spatial ability indicators, the clarity of the language, and their suitability with the learning objectives. Minor revisions were made based on the experts' suggestions. Furthermore, empirical validity was tested through a pilot study involving students outside the research sample. The results indicated that all items had correlation coefficients exceeding the critical value in the r-table, demonstrating statistical validity. The reliability of the instrument was analyzed using Cronbach's Alpha. The analysis produced a coefficient of 0.87, indicating a high level of reliability. Therefore, the instrument was considered sufficiently consistent and reliable for measuring students' spatial abilities.

Data Analysis

The data analysis in this study was conducted in several stages. First, instrument validity and reliability analyses were conducted to ensure the instrument's quality. After data collection, prerequisite tests for normality and homogeneity were conducted. The improvement of students' spatial abilities was calculated using the normalized gain (N-gain) score. Because the data did not fulfill the assumptions of normality and homogeneity, nonparametric statistical tests were employed. The Wilcoxon signed-rank test was used to determine differences between pretest and posttest scores within each group. In contrast, the Mann–Whitney U test was used to analyze differences in improvements in spatial abilities between the experimental and control groups. All statistical analyses were conducted using a significance level of 0.05.

RESULT AND DISCUSSION

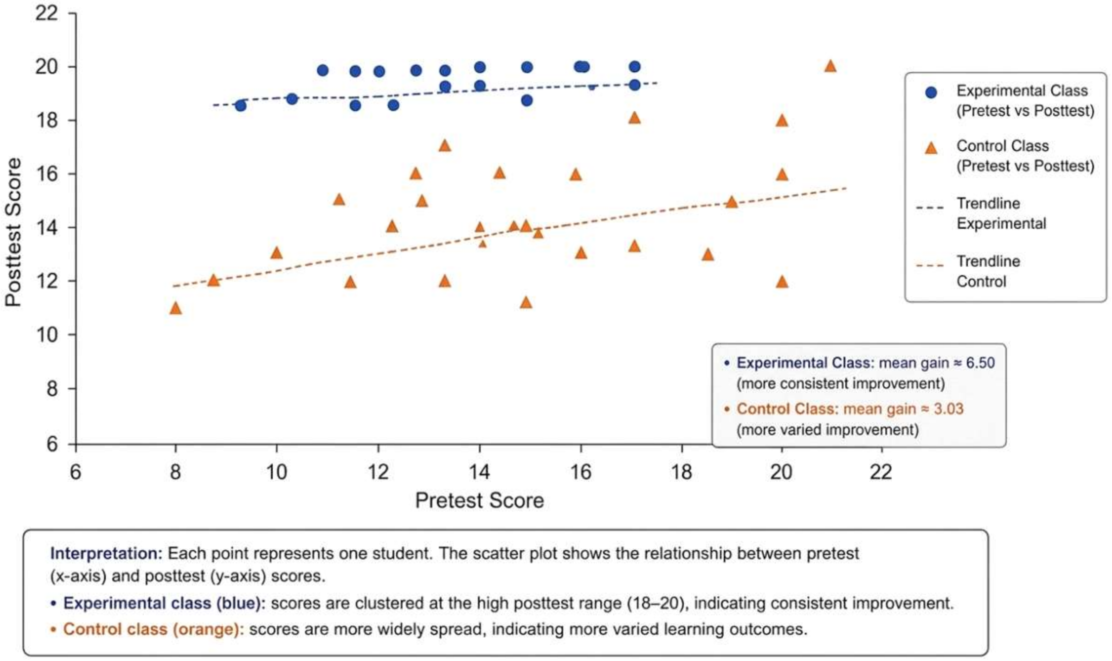
The following Table 1 explains the descriptive analysis of students' spatial abilities, namely:

Table 1. Analysis of students' spatial abilities

	N	Range	Minimum	Maximum	Mean	Std. Deviation
Pretest Eksperimen	34	6	10	20	12.71	1.715
Posttest Eksperimen	34	2	18	20	19.21	0.770
Pretest Kontrol	34	12	8	20	10.71	2.263
Posttest Kontrol	34	23	11	20	13.74	3.895
Valid N (listwise)	34					

The scatter plot was added to provide a clearer representation of the score distribution and individual performance changes between the pretest and posttest results in both classes:

Figure 1 illustrates the scatter plot distribution of students' pretest and posttest scores in both the experimental and control classes. The visualization shows that students in the experimental class experienced a more consistent increase in scores after the treatment, indicated by the clustering of posttest scores in the higher range. In contrast, the control class demonstrated a wider spread of posttest scores, reflecting more varied learning outcomes among students.



Interpretation: Each point represents one student. The scatter plot shows the relationship between pretest (x-axis) and posttest (y-axis) scores.

- **Experimental class (blue):** scores are clustered at the high posttest range (18–20), indicating consistent improvement.
- **Control class (orange):** scores are more widely spread, indicating more varied learning outcomes.

Figure 1. Scatter plot of pretest-posttest scores in experimental and control classes

The descriptive statistical analysis showed that students in the experimental class obtained a mean pretest score of 12.71, with a standard deviation of 1.715, a minimum of 10, and a maximum of 20. These findings indicate that the students' initial spatial abilities were relatively homogeneous and within the moderate category.

After the implementation of the learning treatment, the mean posttest score increased to 19.21, with a standard deviation of 0.770, a minimum of 18, and a maximum of 20. The higher mean score, accompanied by a lower standard deviation, indicates that students' spatial abilities improved substantially and became more evenly distributed after the intervention. The scatter plot further confirms this pattern, as most students' posttest scores in the experimental class were concentrated near the upper end of the score range.

Meanwhile, the control class obtained a mean pretest score of 10.71, with a standard deviation of 2.263, a minimum of 8, and a maximum of 20. After participating in conventional learning, the mean posttest score increased to 13.74, with a standard deviation of 3.895, a minimum of 11, and a maximum of 20. The relatively larger standard deviation in the posttest results indicates that students' achievement in the control class remained more heterogeneous compared to the experimental class. This condition is also reflected in the scatter plot, where the posttest scores in the control class appear more widely dispersed.

Based on the descriptive statistics and scatter plot visualization, the improvement in students' spatial abilities in the experimental class was greater and more consistent than in the control class, indicating that the implemented learning treatment contributed positively to students' spatial ability development.

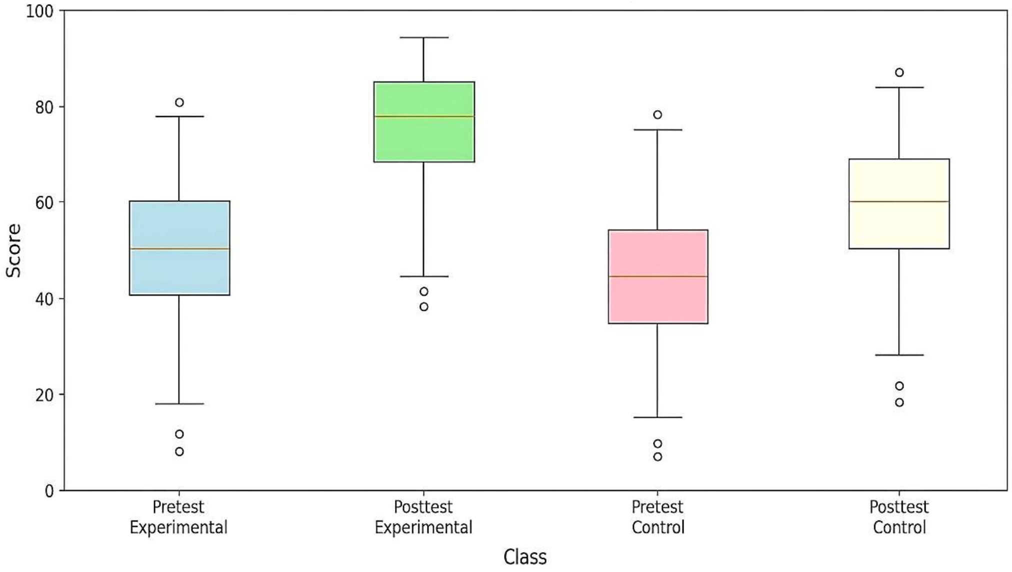


Figure 2. Box plot of pretest and posttest in experimental and control classes

Kolmogorov–Smirnov and Shapiro–Wilk significance scores for all data groups, both in the pretest and posttest of the experimental and control classes. The significance score results for all data groups were below the significance level

Table 2. Normality test

Class		Kolmogorov-Smirnov^a			Shapiro-Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Experimental	Pretest scores	0.189	34	0.003	0.931	34	0.033
Experimental	Posttest scores	0.261	34	0.000	0.792	34	0.000
Control	Pretest scores	0.196	34	0.002	0.806	34	0.000
Control	Posttest scores	0.314	34	0.000	0.508	34	0.000

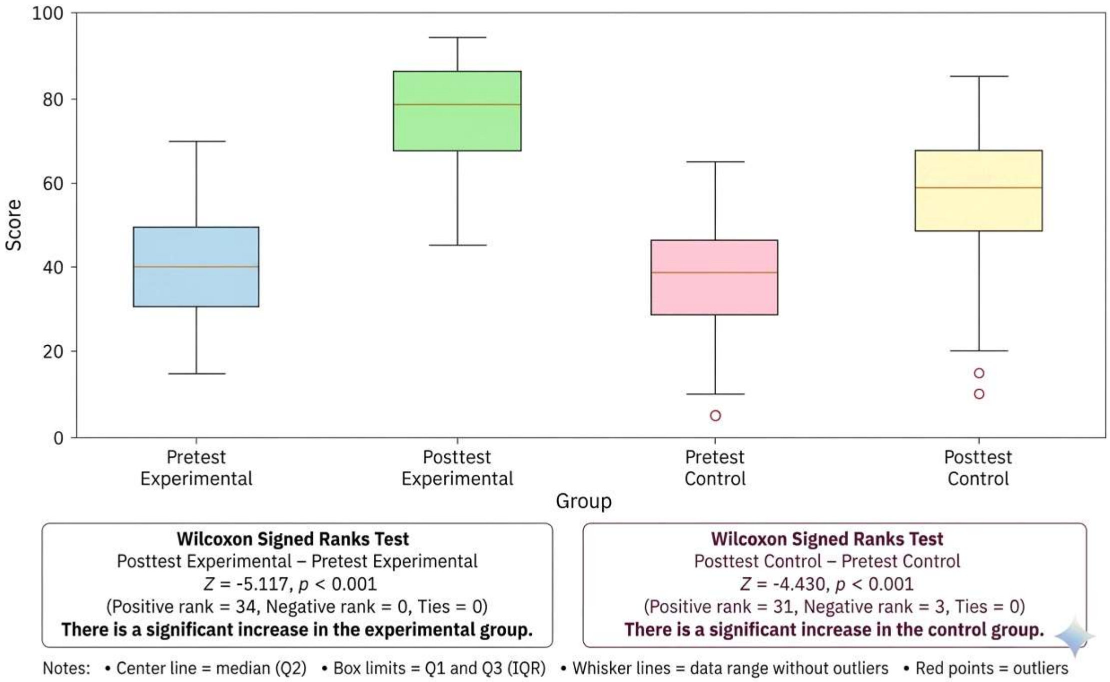
a. Lilliefors Significance Correction

of 0.05. The conclusion drawn is that the spatial ability data from students on the pretest and posttest are not normally distributed. In the experimental class, the pretest results showed a Kolmogorov–Smirnov significance score of 0.003 and a Shapiro–Wilk significance score of 0.033, while in the posttest, the Kolmogorov–Smirnov significance score was 0.000 and the Shapiro–Wilk significance score was 0.000. In the control class, the significance values for the pretest and posttest were all below 0.05. Therefore, the assumption of data normality is not met. Based on these findings, the next data analysis in this study was conducted using the nonparametric Wilcoxon test.

In the experimental class, the results of the Ranks analysis showed that all students (34 students) were in a positive rank. This indicates that the posttest spatial ability scores of students in the experimental class are higher than their pretest scores for all research subjects. In the control class, the Ranks results showed that 31 students experienced an increase in spatial ability (positive ranks), 3 experienced a decrease, and no students had a fixed score. This indicates that although most students in the control class showed an increase in spatial ability after learning, the improvement was uniform across all students.

Table 3. Wilcoxon test to find out the influence of students' spatial abilities

Class	Ranks	N	Mean Rank	Sum of Ranks	Z	P
Experimental	Negative Ranks	0	0.00	0.00	-5.117	<.001
	Positive Ranks	34	17.50	595.00		
	Ties	0				
Control	Negative Ranks	3	14.00	42.00	-4.430	<.001
	Positive Ranks	31	17.84	553.00		
	Ties	0				



Wilcoxon Signed Ranks Test
Posttest Experimental – Pretest Experimental
$Z = -5.117$, $p < 0.001$
(Positive rank = 34, Negative rank = 0, Ties = 0)
There is a significant increase in the experimental group.

Wilcoxon Signed Ranks Test
Posttest Control – Pretest Control
$Z = -4.430$, $p < 0.001$
(Positive rank = 31, Negative rank = 3, Ties = 0)
There is a significant increase in the control group.

Notes: • Center line = median (Q2) • Box limits = Q1 and Q3 (IQR) • Whisker lines = data range without outliers • Red points = outliers

Figure 3. Box plot of pretest and posttest scores in experimental and control groups

The results of the statistical test showed that in the experimental class, a Z score of “5.117 was obtained, while in the control class, a Z score of“4.430 was obtained, with a significance score of 0.000. The conclusion drawn from the application of the Guided Discovery Learning model, assisted by GeoGebra and Kahoot media, provides a stronger and more consistent influence on improving students’ spatial abilities compared to conventional learning.

Table 4. Homogeneity test

Variable	Levene Statistic	df1	df2	Sig.
Results	5.206	1	66	0.026

Based on the homogeneity test using Levene’s Test, the significance value was 0.026, which is lower than 0.05. This result indicates that the variance of the data between the experimental and control classes was not homogeneous.

The results of the Mann–Whitney Test provided an overview of the difference in students’ spatial abilities between the experimental and control classes after receiving the learning treatment. The results of the Ranks analysis explained that the experimental class had a mean rank of 50.50 with a total rank of 1717.00. The control class has a mean rank of 18.50 with a sum of ranks of 629.00. The difference in mean rank scores indicated that the students’ spatial abilities in the experimental class were higher than those in the control class. The results of the Mann–Whitney statistical test were U = 34,000, Z = “6,748, and p = 0.000. The results of this test show that the application of the Guided Discovery Learning model, assisted by GeoGebra and Kahoot media, is significantly more effective at improving students’ spatial abilities than conventional learning.

Table 5. Mann-Whitney test

Class	N	Mean Rank	Sum of Ranks	U	Z	P
Experimental Class	34	50.50	1717.00	34.000	-6.748	<.0001
Control Class	34	18.50	629.00			

To enrich the quantitative findings, a brief qualitative reflection was conducted at the end of the learning intervention involving students from the experimental class. The qualitative data were collected through short open-ended questionnaires distributed after the implementation of Guided Discovery Learning assisted by GeoGebra and Kahoot. The questions explored students’ perceptions regarding the use of GeoGebra in understanding three-dimensional objects and the influence of Kahoot on the classroom learning atmosphere.

The qualitative responses revealed that most students perceived GeoGebra as helpful for visualizing geometric objects that were previously difficult to imagine from static textbook images. Several students stated that the 3D rotation feature enabled them to observe objects from multiple perspectives, making it easier to identify spatial relationships, edges, vertices, and planes. In addition, the dynamic manipulation of geometric models allowed students to explore cube and prism nets interactively, helping them understand the transformation between two-dimensional and three-dimensional representations.

Some students also reported that GeoGebra helped reduce confusion when solving spatial problems by allowing them to directly observe the position and orientation of objects. This finding supports the quantitative results, which showed that the experimental class exhibited a substantial increase in posttest scores and a more homogeneous score distribution after the intervention.

Furthermore, students expressed positive responses toward the use of Kahoot during the learning process. They mentioned that Kahoot created a more enjoyable and competitive classroom atmosphere, increased motivation to learn, and encouraged active participation during discussions and quizzes. Several students explained that the immediate feedback from Kahoot helped them recognize mistakes and improve their understanding during the lesson.

These qualitative findings complement the statistical results by explaining the learning processes underlying the improvement in students' spatial abilities. The integration of GeoGebra and Kahoot not only improved learning outcomes quantitatively but also enhanced students' engagement, motivation, and conceptual understanding during the learning activities.

Table 6. Improvement of spatial ability dimensions

Spatial Ability Dimension	Experimental Class	Control Class	Interpretation
Spatial Visualization	Higher improvement	Moderate improvement	Strong effect of GeoGebra visualization
Spatial Orientation	Improved	Slight improvement	Better perspective understanding

The quantitative improvement in students' spatial abilities was further supported by qualitative responses, which indicated that GeoGebra's dynamic visualization features and Kahoot's interactive learning atmosphere contributed positively to students' conceptual understanding and classroom engagement. Since spatial ability in this study was conceptualized as a multidimensional construct consisting of spatial visualization and spatial orientation, additional analyses were conducted to examine the effect of the learning treatment on each dimension separately. The instrument used in this study included indicators representing both dimensions. Spatial visualization items measured students' ability to mentally manipulate, rotate, and transform two-dimensional and three-dimensional objects, whereas spatial orientation items measured students' ability to recognize and understand object positions from different perspectives and spatial arrangements.

The results showed that both dimensions improved after the implementation of the Guided Discovery Learning model, assisted by GeoGebra and Kahoot media. However, the improvement in the spatial visualization dimension was more pronounced than that in spatial orientation. This finding indicates that the specific features of GeoGebra offer stronger support for activities involving the mental manipulation and transformation of geometric objects. For example, the 3D rotation feature enabled students to rotate geometric solids interactively and observe objects from multiple viewpoints, which directly supported mental rotation skills. In addition, the dynamic net visualization feature allowed students to examine the relationship between two-dimensional nets and three-dimensional forms, helping them mentally reconstruct geometric objects and improve spatial visualization. Students were also able to manipulate object dimensions, reflections, and transformations in real time, making abstract geometric concepts more concrete and cognitively accessible.

From the perspective of Cognitive Load Theory, the dynamic visualization provided by GeoGebra reduced students' extraneous cognitive load because learners no longer needed to rely solely on static textbook images or imagination to interpret spatial relationships. Instead, students could directly observe how shapes changed during transformations, rotations, and perspective shifts. This reduction of unnecessary cognitive processing enabled students to allocate more cognitive resources to essential spatial reasoning activities, particularly those related to visualization and mental manipulation.

In the spatial orientation dimension, students also demonstrated improvement after the treatment, although the increase was relatively more moderate. Spatial orientation requires students to understand object placement and recognize objects from changing perspectives, which involves more complex perspective-taking processes. Guided Discovery Learning contributed to this dimension by encouraging students to actively investigate spatial relationships independently through collaborative exploration and discussion. During learning activities, students analyzed object positions from different viewpoints and compared multiple spatial arrangements, which gradually strengthened their perspective recognition abilities.

Furthermore, the integration of Kahoot indirectly contributed to the development of spatial abilities by increasing motivation, engagement, and concept retention (Tiwari et al., 2024). Kahoot provided immediate feedback during quizzes, allowing students to quickly identify misconceptions related to geometry concepts and spatial relationships (Batubara, 2019). This instant feedback mechanism supports reinforcement learning by allowing students to correct misconceptions before they become permanent. In addition, the gamification elements embedded in Kahoot, such as point accumulation, time challenges, rankings, and competitive interaction, increased students' attention and participation during learning activities. From the perspective of motivational learning theory, these elements promoted active engagement and sustained concentration, both of which are important for strengthening conceptual understanding and long-term retention of spatial concepts. As students became more motivated and actively involved in the learning process, they were more likely to repeatedly process spatial information, thereby improving their spatial reasoning performance (Chikiwa & Schäfer, 2021).

The findings of this study are also consistent with the Technological Pedagogical Content Knowledge (TPACK) framework, which emphasizes that effective technology integration occurs when technological tools, pedagogical strategies, and subject matter knowledge are interconnected. In this study, GeoGebra served not merely as a visualization tool but as a medium aligned with the pedagogical principles of Guided Discovery Learning, enabling students to explore, manipulate, and construct geometric concepts independently. Kahoot complemented this process by supporting formative assessment and maintaining student engagement throughout the learning activities (Jian & Abu Bakar, 2024). The integration of these technologies created a more interactive and student-centered learning environment that facilitated conceptual understanding and active knowledge construction.

The results of this study reinforce previous findings showing that technology-assisted discovery learning environments are effective in improving students' spatial abilities. This is the same Noverianto et al. (2024), which states that dynamic geometry software improves students' visualization and spatial reasoning skills more effectively than conventional learning environments. The research conducted by Devi & Rajeswari (2024) found that GeoGebra-assisted learning significantly improved junior high school students' spatial abilities because the media allowed students to interact directly with geometric representations attractively and flexibly. Previous studies also reported that Kahoot-based game learning increases participation, motivation, and mathematics learning outcomes through interactive and competitive learning experiences (Putri et al., 2021). The results of the study reinforce several previous studies that found discovery-based learning combined with interactive technology media is more effective at improving students' spatial abilities.

Overall, the findings indicate that the greater improvement in spatial visualization than in spatial orientation may be attributed to the nature of GeoGebra itself, which particularly supports dynamic visual manipulation and the mental transformation of objects (Nurwijayanti, 2019). The combination of Guided Discovery Learning, GeoGebra, and Kahoot therefore not only improved students' spatial ability in general but also specifically strengthened the cognitive processes involved in visualization, mental rotation, concept retention, and active spatial reasoning.

■ LIMITATIONS

This study has several limitations that should be considered when interpreting the findings. First, the improvement in students' spatial abilities may not have been solely attributable to the implementation of the GeoGebra- and Kahoot-assisted Guided Discovery Learning model. Other external factors, such as students' motivation to learn, prior technological familiarity, classroom environment, and teacher interaction, may also have contributed to the learning outcomes.

Second, the study may have been affected by the Hawthorne effect, in which students in the experimental class demonstrated higher engagement and performance because they were aware they were receiving a different, technology-supported learning treatment. The use of interactive applications such as GeoGebra and Kahoot may have temporarily increased students' enthusiasm during the intervention period.

Third, this research involved a limited number of participants from a single school, which may reduce the generalizability of the findings to broader educational contexts. In addition, the sampling process used intact classroom groups, which may potentially introduce sampling bias because students were not randomly assigned individually to the experimental and control groups.

Furthermore, the intervention was relatively short, so the long-term impact of the learning model on students' spatial abilities could not be fully examined. Future studies are recommended to involve larger, more diverse samples, use longer intervention periods, and investigate additional variables such as learning motivation, digital literacy, and students' retention of spatial ability over time. Further research may also compare GeoGebra and Kahoot-assisted Guided Discovery Learning with other technology-integrated instructional models to obtain a more comprehensive understanding of its effectiveness in mathematics learning.

■ CONCLUSION

The findings of this study indicate that students who participated in the Guided Discovery Learning model assisted by GeoGebra and Kahoot demonstrated higher spatial ability scores after the learning intervention. The integration of interactive technology and guided discovery activities was associated with more active student participation, improved visualization of geometric concepts, and more homogeneous learning outcomes in the experimental class. These findings suggest that the combination of GeoGebra, Kahoot, and Guided Discovery Learning has the potential to support mathematics learning, particularly in developing students' spatial abilities within the context of this study.

However, the conclusions of this research should be interpreted carefully due to several methodological limitations. The use of purposive sampling and the involvement of participants from only one school limit the generalizability of the findings to broader educational populations. In addition, the relatively short duration of the intervention and potential external influences, such as students' motivation and the Hawthorne effect, may have affected the results. Therefore, this study does not claim a definitive causal relationship, but rather indicates an association between the implemented learning model and the observed improvement in students' spatial abilities. Future research is recommended to involve larger, more diverse samples, use random sampling techniques, and explore the long-term effects of technology-assisted Guided Discovery Learning in mathematics education.

■ REFERENCES

Batubara, I. H. (2019). Improving students' critical thinking ability through guided discovery learning methods assisted by GeoGebra. *International Journal for Educational and Vocational Studies, 1*(2), 116-119. https://doi.org/10.29103/ijevs.v1i2.1371

Changwong, K., Sukkamart, A., & Sisan, B. (2021). Critical Thinking Skill Development: Analysis Of A New Learning Management Model For Thai High Schools. *Journal of International Studies, 11*(2), 37–48. https://doi.Org/10.14254/2071-8330.2018/11-2/3.

Chikiwa, C., & Schäfer, M. (2021). Promoting Critical Thinking In Multilingual Mathematics Classes Through Questioning. *Eurasia Journal Of Mathematics, Science And Technology Education, 14*(8), 17. https://doi.Org/10.29333/Ejmste/91832

Cui, X., & Guo, K. (2022). Supporting mathematics learning: a review of spatial abilities from research to practice. *Current Opinion in Behavioral Sciences, 46*, 101176. https://doi.org/10.1016/j.cobeha.2022.101176

Del Cerro Velázquez, F., & Morales Méndez, G. (2021). Systematic review of the development of spatial intelligence through augmented reality in STEM knowledge areas. *Mathematics, 9*(23), 3067. https://doi.org/10.3390/math9233067

Di, X., & Zheng, X. (2022). A meta-analysis of the impact of virtual technologies on students' spatial ability. *Educational technology research and development, 70*(1), 73–98. https://doi.org/10.1007/s11423-022-10082-3

English, L. D. (2023). Ways of thinking in STEM-based problem solving. *ZDM–Mathematics Education, 55*(7), 1219–1230. https://doi.org/10.1007/s11858-023-01474-7

Gittinger, M., & Wiesche, D. (2024). Systematic review of spatial abilities and virtual reality: The role of interaction. *Journal of Engineering Education, 113*(4), 919–938. https://doi.org/10.1002/jee.20568

Gourdeau, F. (2015). Doing Mathematics in Teacher Preparation: Giving Space and Time to Think, Reflect, Share, and Feel. In: Cho, S. (eds) Selected Regular Lectures from *the 12th International Congress on Mathematical Education*. Springer, Cham. https://doi.org/10.1007/978-3-319-17187-6_13

Hattie, J. A. C., & Donoghue, G. M. (2019). Learning Strategies: A Synthesis And Conceptual Model. *Npj Science of Learning, 1*(1), 18. https://doi.Org/10.1038/Npjscilearn.2016.13

Harris, D. (2023). Spatial reasoning in context: bridging cognitive and educational perspectives of spatial-mathematics relations. *Frontiers in Education, 8*(1302099). https://doi.org/10.3389/feduc.2023.1302099

Jian, Y., & Abu Bakar, J. A. (2024). Comparing cognitive load in learning spatial ability: immersive learning environment vs. digital learning media. *Discover Sustainability, 5*(1), 111. https://doi.org/10.1007/s43621-024-00310-6

Jiménez Sierra ÁA, Ortega Iglesias JM, Cabero-Almenara J and Palacios-Rodríguez A (2023). Development of the teacher's technological pedagogical content knowledge (TPACK) from the Lesson Study: A systematic review. *Front. Educ. 8*, 1078913. https://doi.org/10.3389/feduc.2023.1078913

Kalogiannakis, M., Papadakis, S., & Zourmpakis, A. I. (2021). Gamification in science education. A systematic review of the literature. *Education Sciences, 11*(1), 22. https://doi.org/10.3390/educsci11010022

Lapenok, M.V., Lozinskaya, A.M., Shestakova, L.G., Voronina, L.V., Zuev, P.V., Patrusheva, O.M. (2019). The Methodology of Development of Electronic Educational Resources for Learning of General Scientific Disciplines in Non-native Language. In: Uskov, V., Howlett, R., Jain, L. (eds) Smart Education and e-Learning 2019. *Smart Innovation, Systems and Technologies, 144*. https://doi.org/10.1007/978-981-13-8260-4_12.

Li, M., & Li, B. (2024). Unravelling the dynamics of technology integration in mathematics education: A structural equation modelling analysis of TPACK components. *Education and Information Technologies, 29*(17), 23687-23715. https://doi.org/10.1007/s10639-024-12805-w

Noverianto, B., Agoestanto, A., Dewi, N. R., & Mariani, S. (2024). Meta Analysis: The Effect of The Geogebra Applet-Assisted Discovery Learning Model on Students' Mathematical Problem Solving Ability in Geometry Material. *Mathline : Jurnal Matematika Dan Pendidikan Matematika, 9*(2), 331–346. https://doi.org/10.31943/mathline.v9i2.604

Nurwijayanti, A., Budiyono, & Fitriana, L. (2019). Combining Google SketchUp and iSpring Suite 8: A breakthrough to develop geometry learning media. *Journal on Mathematics Education*, *10*(1), 103–115. https://doi.org/10.22342/jme.10.1.5380.103-116

N.V. Poornima Devi, & Dr. A. Rajeswari. (2024). Visualizing Algebra, Enhancing Minds: A Quasi-Experimental Evaluation Of Geogebra's Role In Reducing Cognitive Load And Improving Problem-Solving Skills. *Educational Administration: Theory and Practice, 30*(7), 1417–1421. https://doi.org/10.53555/kuey.v30i7.10359

Oliveira, H., Mendes, F., & Henriques, A. . (2022). A investigação sobre o ensino e a aprendizagem de temas matemáticos publicada em 30 anos da revista Quadrante. *Quadrante, 31*(2), 32–62. https://doi.org/10.48489/quadrante.28086

Papakostas, C., Troussas, C., Krouska, A., & Sgouropoulou, C. (2021). Exploration of augmented reality in spatial abilities training: a systematic literature review for the last decade. *Informatics in Education, 20*(1), 107–130.

Pishtari, G., Ley, T., Khalil, M., Kasepalu, R., & Tuvi, I. (2023). Model-Based Learning Analytics for a Partnership of Teachers and Intelligent Systems: A Bibliometric Systematic Review. *Education Sciences, 13*(5), 498. https://doi.org/10.3390/educsci13050498

Putri, N. R., Sabandar, J., & Sugandi, A. I. (2021). The Development of Teaching Materials on the Area of Triangles and Quadrilaterals Using the GeoGebra-Assisted Discovery Learning Method to

Improve Mathematics Understanding Ability. *(JIML) Journal of Innovative Mathematics Learning, 4*(3), 132–141.

Schenck, K. (2022). *Connecting Mathematics, Spatial Ability, and Spatial Anxiety. 2016*. https://doi.org/10.3102/1570419

Schenck, K. E., & Nathan, M. J. (2024). Navigating spatial ability for mathematics education: A review and roadmap. *Educational Psychology Review, 36*(3), 90. https://doi.org/10.1007/s10648-024-09935-5

Tiwari, S., Shah, B., & Muthiah, A. (2024). A global overview of SVA—Spatial–Visual ability. *Applied System Innovation, 7*(3), 48. https://doi.org/10.3390/asi7030048

Xie, F., Zhang, L., Chen, X., & Xin, Z. (2020). Is spatial ability related to mathematical ability: A meta-analysis. *Educational Psychology Review, 32*(1), 113–155. https://doi.org/10.1007/s10648-019-09496-y

Yang, Y., Du, W., Mavrikis, M., & Geraniou, E. (2025). Spatial skill development through augmented reality in mathematics education: A scoping review. *Digital Experiences in Mathematics Education*, 1–34. https://doi.org/10.1007/s40751-025-00187-8

Yilmaz, B., & Yilmaz, H. B. (2017). On the development and measurement of spatial ability. *International Electronic Journal of Elementary Education*, *1*(2), 83–96.

Zhang, Y., Wang, P., Jia, W., Zhang, A., & Chen, G. (2025). Dynamic visualization by GeoGebra for mathematics learning: a meta-analysis of 20 years of research. *Journal of Research on Technology in Education, 57*(2), 437–458. https://doi.org/10.1080/15391523.2023.2250886

Zulhafendi, R. W., & Yarman. (2026). Improving Mathematical Reasoning Through Geogebra-Assisted Discovery Learning. *Jurnal PAJAR (Pendidikan dan Pengajaran), 10*(2), 179–190. https://doi.org/10.33578/pjr.v10i2.385