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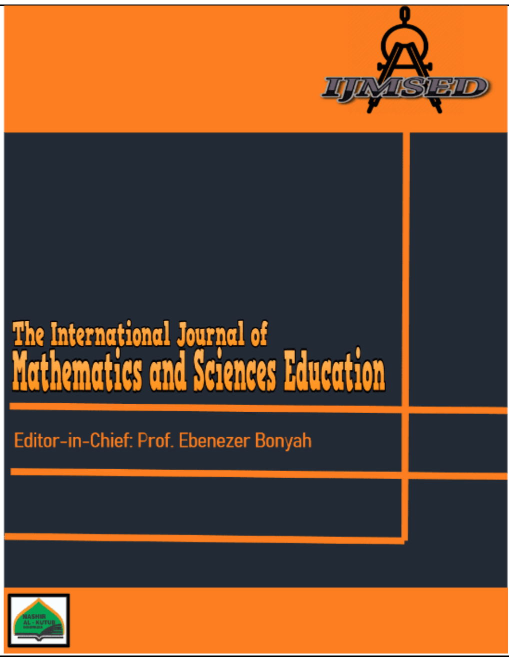

Visualizing geometry: exploring the role of geogebra-assisted 6E-IM model in enhancing students' spatial abilities

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Visualizing geometry: exploring the role of geogebra-assisted 6E-IM model in enhancing students' spatial abilities

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Abstrac
Students' spatial visualization ability is a key component in understanding geometry, yet many students exhibit suboptimal performance in this area. This study aimed to (1) evaluate the quality of the Geogebra-assisted 6E-IM learning model, (2) examine its effect on students' spatial visualization ability, and (3) describe students' ability levels after receiving the intervention. A sequential explanatory mixed-methods design was used. The independent variable was the Geogebra-assisted 6E-IM model, while the dependent variable was students' spatial visualization ability. A total of 60 students participated, with 30 assigned to the experimental group and 30 to the control group. Data were collected through tests, interviews, and questionnaires. Quantitative results showed that students in the experimental group significantly outperformed the control group ($p < 0.05$), indicating a positive effect of the Geogebra-assisted 6E-IM model on spatial visualization ability. Qualitative analysis revealed that students with high ability met all spatial visualization indicators; those with moderate ability met two indicators, while those with low ability met only one. These findings demonstrate that the integration of Geogebra in the 6E-IM learning model can effectively enhance students' spatial visualization skills in geometry. This study contributes to the development of innovative, technology-integrated instructional strategies in mathematics education.

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1. Introduction

Students' spatial visual ability is one of the key factors in learning geometry, especially in understanding plane and spatial shapes (Sudirman & Alghadari, 2020; Yenilmez & Kakmaci, 2015).). However, many students face difficulties in developing this spatial visual ability. This can be seen from their inability to visualize and imagine geometric objects, which ultimately hinders their understanding and learning achievement (Lowrie et al., 2019). Gutiérrez (2017) added that spatial ability consists of two main components: spatial orientation and spatial visualization. However, geometry is often a mathematical material that is considered difficult by students and requires spatial visual ability to solve geometric problems. Therefore, enhancing students' spatial visual ability through effective instructional strategies is essential to improve their performance in geometry.

The ability of spatial visualization plays a crucial role in comprehending geometric relationships and identifying the characteristics of both two-dimensional and three-dimensional shapes. This cognitive skill enables students to mentally manipulate, rotate, and analyze geometric objects, which is essential in solving mathematical problems, particularly those involving spatial reasoning (Buckley et al., 2019). However, challenges frequently emerge in geometry topics—such as prisms—where students are required to understand the intricate relationships among various elements of spatial figures, including faces, edges, and vertices. Research by Arfani (2016) indicates that a significant number of students struggle to grasp abstract geometric concepts, particularly those related to three-dimensional shapes. These difficulties are further supported by the findings of Novitasari et al. (2019), who reported that students often face challenges in distinguishing and accurately identifying the elements of spatial objects, which hampers their overall comprehension and problem-solving ability in geometry.

In general, low spatial visual ability among students is a common phenomenon encountered across various levels of education, from primary to secondary schools. Research conducted by Sarama and Clements (2009) highlights that limitations in spatial visualization significantly impede the development of geometric understanding, which is foundational to success in mathematics education. These difficulties are not merely due to individual cognitive factors, but are often compounded by instructional approaches that are predominantly monotonous, abstract, and lacking in interactivity. As a result, students are deprived of meaningful opportunities to explore and enhance their spatial thinking through concrete experiences or dynamic representations (Uttal et al., 2012). In this regard, many educational experts have emphasized the critical role of instructional media that effectively supports visualization processes in mathematics learning (Yilmaz & Argun, 2018). Such media not only aid in bridging abstract concepts with tangible representations but also stimulate students' engagement, curiosity, and spatial reasoning skills—factors that are essential for mastering geometric concepts.

Based on observations and interviews with several mathematics teachers at SMP Negeri 3 Kahayan Tengah during the odd semester of the 2023/2024 Academic Year, it was revealed that the learning methods adopted by these teachers were generally uniform, including lectures, group discussions, and question and answer sessions. Field observations showed that the mathematical problem-solving abilities of junior high school students, especially class VII-B, were still low. This can be seen from the results of the mid-semester assessment which showed that only 18% of students achieved the minimum completeness criteria on the Prisma material. In addition, researchers observed that most students had weak self-control in dealing with mathematics problems. They tend to avoid difficulties, are reluctant to ask questions, and copy friends' work. This low problem-solving ability and self-confidence can hinder students' learning achievement. Therefore, it is important to develop students' visual spatial abilities so that they are able to face challenges and improve their learning achievement.

Several previous studies support and align with the focus of this research. For instance, Sudirman et al (2022) based on a paired sample t-test, showed that the integration of the 6E Instructional Model with Augmented Reality (AR) significantly improved the 3D geometric representation abilities of eighth-grade students at a private school in Indramayu Regency. The current research differs in terms of the technological tool used, where the author employed GeoGebra as the primary learning aid rather than AR. Similarly, a study by Simbolon (2020) reported improvements in student engagement and a rise in the number of students achieving the minimum passing grade in each cycle. However, the present research differs in terms of methodology, as it adopts a sequential explanatory approach. Additionally, the learning model applied in the author's research diverges from that of Simbolon's study, reflecting a different pedagogical design and implementation.

The urgency of this research lies in the need to explore in greater depth the strengths and weaknesses of students when learning geometry through the 6E Instructional Model (6E-IM) assisted by GeoGebra. Geometry, as one of the abstract branches of mathematics, requires not only conceptual understanding but also strong spatial visual skills—abilities that are often developed through appropriate pedagogical strategies and the use of dynamic visualization tools. The integration of 6E-IM, which emphasizes exploration, elaboration, and evaluation stages, with GeoGebra as a technological aid, provides a promising approach to accommodate diverse student learning styles. Through this study, it is expected that a clearer picture will emerge regarding how students with different cognitive tendencies respond to this learning model, thereby identifying specific strengths that can be optimized and weaknesses that need to be addressed. The findings are expected to serve as valuable input for teachers, enabling them to more accurately identify students' learning preferences and tailor instructional designs accordingly. In the long term, this will contribute to more inclusive, responsive, and effective mathematics instruction that not only improves learning outcomes but also fosters positive learning experiences for all students.

Based on the background of the problem that has been explained above, the formulation of the problem of this study is: (1) How is the design of 6E-IM assisted by GeoGebra to improve students' visual spatial abilities in Prisma material? (2) Is there a difference in improving visual spatial abilities between students who learn using the 6E-IM model assisted by Geogebra and only using 6E-IM?

2. Method

This study employs a mixed methods approach with a concurrent embedded design, a model that allows researchers to collect and analyze both quantitative and qualitative data simultaneously within a single study framework, while assigning different weights to each method. According to Hairil (2021), the embedded design is characterized by the integration of two research paradigms—quantitative and qualitative—where one serves as the primary method and the other as the secondary method. The primary method is used to generate the main findings, while the secondary method provides supplementary data to support or elaborate on the primary results. In this study, the quantitative method is positioned as the dominant or primary approach, and is implemented through a quasi-experimental design to test research hypotheses and perform statistical analyses. In contrast, the qualitative method functions as a complementary strategy to gain deeper insight into students' learning experiences, behaviors, and perceptions during the implementation of the 6E Instructional Model (6E-IM) integrated with GeoGebra. This dual approach is intended to provide a more comprehensive and nuanced understanding of the phenomenon under investigation, as supported by Creswell (2018), who emphasizes the value of mixed methods in educational research for capturing both measurable outcomes and contextual interpretations.

The population in this study comprises all seventh-grade students at SMP X, totaling 90 students. A purposive sampling technique was used to select participants, resulting in two groups: an experimental group and a control group, each consisting of 30 students. The grouping process was carefully conducted by taking into account students' previous mathematics performance based on their odd semester grades to ensure that both groups were balanced in terms of initial mathematical ability. This stratification was crucial to minimize potential biases and enhance the validity of the experimental findings.

To meet the requirements for statistical analysis, a series of assumption tests were conducted. The normality of the data was assessed using the Shapiro-Wilk test, with a significance level of $\alpha = 0.05$. This test was deemed appropriate given that the sample size in each group was fewer than 50 participants. Following this, a homogeneity test was performed using the Levene's test, also at a 0.05 significance level, to determine whether the variances between groups were statistically equivalent. After confirming the assumptions of normality and homogeneity, the study proceeded with hypothesis testing. The independent sample t-test was employed to analyze the differences in outcomes between the experimental and control groups, thereby evaluating the effectiveness of the 6E-IM learning model assisted by GeoGebra in enhancing students' geometric understanding. This analytical framework is grounded in the procedures outlined by Arikunto (2021), who underscores the importance of using appropriate statistical tests to derive meaningful and valid conclusions in educational research.

3. Results and Discussion

3.1 Results

The research steps carried out consist of (1) analysis of student difficulties in learning the geometry material of prisms; (2) compiling 6E-IM assisted by Geogebra, (3) limited testing; (4) providing student response questionnaires; (5) validation by experts; and (6) field testing. An overview of each stage can be described as follows:

3.1.1 Initial Overview of Students' Difficulties in Understanding Geometry Material

Other factors that can cause students to experience difficulties can come from external factors, such as from the teacher who teaches. Based on interviews that have been conducted, the questions given by the teacher to students have been directed towards problem-solving questions and based on the results of observations, the learning carried out by the teacher has required students to be active and construct their own knowledge, but the teacher's follow-up to students who experience difficulties has not been carried out. This causes students who have difficulty solving a problem to continue to experience difficulties if given a similar problem.

The findings are also reinforced by the percentage of students who cannot answer questions correctly. This can be seen in Table 1.

Table 1

Percentage of Students Who Could Not Answer Correctly

No	Question Indicator	Total Students	Percentage of students who could not answer correctly	
			Amount	(%)
1	Identify models or objects related to prisms.	30	25	83,3
2	Identifying the elements of a prism	30	21	70
3	Breaking down geometric shapes into smaller ones (nets)	30	22	73,3
4	Students can determine how to find the surface area of a prism.	30	24	80
5	Students can determine how to find the volume of a prism.	30	23	76,6

Source: Pretest results of control class students at SMPN 3 Kahayan Tengah

The results from the table indicate that students face significant difficulties in various aspects of understanding the concept of prisms. Out of 30 students, 25 (83.3%) were unable to correctly identify models or objects related to prisms, demonstrating a limited initial understanding of three-dimensional geometric shapes. Furthermore, 21 students (70%) struggled to correctly identify the elements of a prism, indicating a lack of comprehension regarding the fundamental components such as faces, edges, and vertices. The ability to decompose a prism into its net was also a major challenge, with 22 students (73.3%) unable to do so accurately. This highlights students' difficulty in transforming three-dimensional spatial representations into two-dimensional forms, which is essential for a deeper understanding of prism structure. Additionally, procedural knowledge such as determining how to calculate the surface area of a prism posed a high level of difficulty, with 24 students (80%) failing to answer correctly. Similarly, 23 students (76.6%) could not correctly determine how to find the volume of a prism. Overall, these findings emphasize that students' understanding of prisms — from recognizing shapes and elements to visualizing nets and applying basic geometric formulas — remains insufficient. This situation calls for more effective and interactive learning approaches, such as the use of visualization tools or educational technology, to support the development of students' spatial and conceptual abilities in three-dimensional geometry.

If examined more deeply, the large number of students who answered incorrectly indicates that students experience epistemological obstacles in carrying out a series of 3D geometric thinking tasks, for example in representing 3D geometric objects, determining the spatial structure of 3D geometry, and measuring the surface area and volume of 3D geometry.

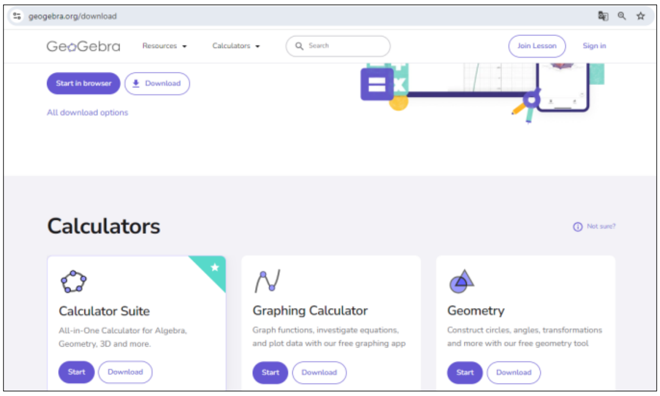
3.1.2 GeoGebra software to improve spatial visual skills

Geogebra was developed by Markus Hohenwarter (June 24, 1976) starting in 2001. He is an Austrian mathematician and professor at Johannes Kepler University (JKU) Linz. The benefits of Geogebra include (Lakusa et al., 2023):

a) Can produce geometric drawings quickly and accurately, even complex ones.
b) The existence of animation facilities and manipulation movements that can provide a visual experience in understanding geometric concepts.
c) Can be used as feedback/evaluation material to ensure that the geometric drawings that have been made are correct.
d) Makes it easier to investigate or show the properties that apply to a geometric object. Geogebra continues to develop.

Geogebra can be used both online (without installation) and with installation on the device. The way to get GeoGebra is quite easy, you can visit the page https://www.geogebra.org/download then select the version of GeoGebra to be installed according to the device's operating system. At least until now (September 2024) there are six types of GeoGebra. The six types of GeoGebra are Calculator Suite, Graphing Calculator, Geometry, 3D Calculator, CAS Calculator, and Scientific Calculator as seen in Figure 1.

Figure 1
Dashboard Geogebra

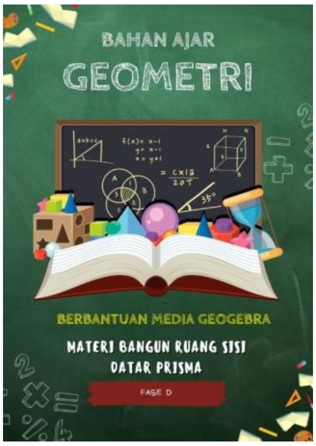


Each GeoGebra has different complete features, here are the differences in features owned by the six types of GeoGebra. Calculator Suite is a type of GeoGebra with the most complete features compared to other types of GeoGebra.

3.1.3 Geometry Teaching Material Design with the 6E-IM Model assisted by Geogebra

The front page of the teaching material consists of a cover, foreword, table of contents, instructions for using the material, concept maps, learning objectives, let's get to know the characters, and the contents of the material for each meeting. The cover of the Geogebra-assisted geometry teaching material can be seen in Figure 2.

Figure 2
Cover teaching materials



The purpose of assigning a specific title to the cover of the GeoGebra-assisted geometry teaching materials is to clearly distinguish these materials from other conventional or non-assisted teaching resources. This differentiation not only helps students and educators easily identify the unique features and technological integration within the materials but also emphasizes the innovative approach employed in delivering geometry content. Additionally, a distinct title serves as a form of branding that highlights the use of GeoGebra as a dynamic tool to enhance students' spatial visualization and interactive learning experiences, setting it apart from traditional textbooks or worksheets.

The page in the content section is divided into nine main materials. The distribution of these materials can be seen in Table 2.

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Table 2
Distribution of Materials and Meetings

Meetings	Learning objectives
Day-1	Introduction to GeoGebra in Mathematics Learning
Day-2	Learning Activity Design using Geogebra
Day-3	Students can create prism, cuboid and cube nets
Day-4	Students can calculate the surface area of a prism
Day-5	Students can calculate the volume of a prism
Day-6	Evaluation

The table outlines a six-day learning plan focused on integrating GeoGebra into mathematics instruction, particularly on geometry topics. On the first day, students are introduced to GeoGebra and its role in supporting interactive mathematics learning. The second day emphasizes designing learning activities using GeoGebra, helping both teachers and students to understand how to effectively utilize the software's features. On the third day, students engage in creating nets of three-dimensional shapes such as prisms, cuboids, and cubes using GeoGebra, which is essential for developing their spatial visualization skills. The fourth and fifth days focus on calculating the surface area and volume of prisms respectively, with GeoGebra serving as a learning tool to facilitate conceptual understanding and mathematical calculations. Finally, on the sixth day, an evaluation is conducted to assess students' comprehension of the material and the effectiveness of using GeoGebra in the learning process.

3.1.4 Design 6E-IM with Geogebra

The GeoGebra-assisted 6E Instructional Model (6E-IM) is carefully structured around six key phases: elicit, engage, explore, explain, elaborate, and evaluate. Each phase plays a crucial role in fostering a deeper understanding of geometric concepts by encouraging students to actively participate and construct knowledge step-by-step. The "elicit" phase aims to uncover students' prior knowledge and misconceptions, while "engage" captures their interest and motivates them to learn. During "explore," students interact directly with GeoGebra tools to investigate geometric objects, which is followed by the "explain" phase where they articulate their findings and understanding. The "elaborate" phase challenges students to apply their knowledge to new problems, and finally, "evaluate" assesses their comprehension and learning progress. By embedding GeoGebra technology into each phase, the model enhances visualization, making abstract geometry concepts more concrete and accessible.

This instructional design draws heavily on the principles of Realistic Mathematics Education (RME), which advocates for teaching mathematics through contexts that are meaningful and relevant to students' everyday experiences. By combining RME with modern Information and Communication Technology (ICT), particularly the dynamic and interactive GeoGebra software, the model bridges conceptual understanding with practical application. GeoGebra serves as a powerful tool that allows students to manipulate geometric figures, observe properties dynamically, and test hypotheses in real time. This integration supports varied learning styles and helps overcome common difficulties in spatial visualization and geometry comprehension.

The GeoGebra-assisted 6E-IM specifically targets the teaching of critical topics related to three-dimensional geometry, focusing on triangular prisms, cuboids, and cubes. The learning objectives encompass (1) identifying and understanding the elements and properties of these solid figures, such as faces, edges, and vertices; (2) accurately drawing the shapes to develop spatial reasoning; (3) constructing nets (jaring-jaring) to bridge 3D shapes with their 2D representations; (4) calculating surface areas, which involves understanding the sum of the areas of all faces; and (5) determining volumes, emphasizing the measurement of space occupied by these solids. By addressing these comprehensive objectives through the 6E-IM framework assisted by GeoGebra, the learning experience becomes more interactive, meaningful, and effective in building students' geometric thinking skills.

3.1.5 Expert Validation Limited Testing Overview

The learning device and research instruments were carefully reviewed and validated by a panel consisting of the school principal, two mathematics teachers, and one guidance and counseling teacher. This validation process aimed to ensure the relevance, clarity, and effectiveness of the tools used in the study. A summary of the validation results for the research instruments is presented in Table 3.

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Table 3
Recapitulation of Learning Device Validation

Learning Tool	Validator 1	Validator 2	Validator 3	Description
Teaching module	89%	94.5%	92.7%	All learning devices are categorized as "very good"
Student Worksheet	90%	91.25%	91.25%	
Pre-test	90%	94%	96%	
Post-test	90%	94%	100%	
Spatial visual ability questionnaire	91.4%	100%	91.4%	
Interview guidelines	84%	96%	96%	
Observation	90%	100%	93.3%	

Table 3 presents the validation results of various learning tools as assessed by three validators. The learning tools evaluated include the teaching module, student worksheet, pre-test, post-test, spatial visual ability questionnaire, interview guidelines, and observation checklist. The percentage scores given by each validator indicate a consistently high level of quality across all tools, with values ranging from 84% to 100%. Notably, the teaching module received scores between 89% and 94.5%, while the pre-test and post-test instruments scored even higher, with the post-test reaching up to 100% from Validator 3. The spatial visual ability questionnaire and observation tools also achieved strong validation scores, confirming their suitability for use in the research.

Based on these validation percentages, all learning tools are categorized as "very good" and deemed valid for implementation in the study. This means that the instruments have met the criteria required for reliability and effectiveness in supporting the research objectives. Consequently, these validated tools were employed during the learning process in the experimental group, which utilized the 6E Instructional Model assisted by GeoGebra. The strong validation results ensure that the data collected through these instruments accurately reflect students' learning progress and experiences within the GeoGebra-enhanced instructional framework.

3.1.6 Field Testing

In accordance with the Learning Implementation Plan in the school curriculum, the implementation of learning takes place for seven meetings. Eight meetings for delivering materials and one meeting for evaluation. Based on the overall observation results, the training process took place without any obstacles. However, there were some students whose mobile phones did not support scanning QR Codes. Furthermore, when the teacher explained the use of 3D geometry teaching materials assisted by GeoGebra, it was seen that students had understood the process of using it well. The process is shown in Figure 3.

Figure 3
Explanation to students regarding Geogebra

The implementation of learning in general has gone well and in accordance with the teaching module that has been created. All learning content at each meeting was delivered and all stages in the 6E-IM model assisted by geogebra, as evidenced by the results of observations at the first and second meetings. The complete observation sheet for the implementation of the 6E-IM model learning assisted by geogebra can be seen in the Appendix. The summary of the results of observations of the implementation of the 6E-IM model learning assisted by geogebra from the first to sixth meetings can be seen in the Table 4.

Table 4
Student Learning Observation Results

Meeting	Average	Nilai Keterlaksanaan (%)	Kriteria
I	35.63	89.0%	High
II	31.7	79.2%	High
III	32.9	82.2%	High
IV	33.13	82.8%	High
V	32.13	80.3%	High
VI	31.7	79.2%	High

Table 4 above shows that the teacher's ability to manage learning in the first to sixth meetings is categorized as high. Thus, it can be concluded that all learning with the 6E-IM model assisted by Geogebra was carried out very well.

After the implementation of the learning process and administration of the visual-spatial ability test to students, post-test data were collected and subsequently analyzed to draw meaningful conclusions regarding the effectiveness of the applied instructional model. Prior to hypothesis testing, prerequisite tests were conducted to determine the suitability of the data for parametric analysis. These included tests of normality and homogeneity, both essential in ensuring the validity of the subsequent statistical procedures.

The normality of the data was assessed using the Shapiro-Wilk test, assisted by the SPSS software at a significance level of 0.05. The results indicated that the significance value for the experimental class was 0.083, and for the control class was 0.064. Since both values exceeded the threshold of 0.05, the null hypothesis (H_0) was accepted, suggesting that the visual-spatial ability scores in both groups were normally distributed. This finding supports the use of further parametric tests for comparative analysis.

To ensure equality of variance between the two groups, a homogeneity test was conducted using Levene's test. The analysis yielded a significance value of 0.411, which is above the critical value of 0.05. Hence, H_0 was again accepted, confirming that there were no significant differences in variance between the experimental and control groups. This establishes that the data from both groups are homogeneous, meeting the assumption required for the t_{test}.

Following the confirmation of normality and homogeneity, a t-test was performed to examine the hypothesis regarding the effectiveness of the 6E-IM assisted by GeoGebra in enhancing students' visual-spatial abilities. The result showed a t-count of 5.28, which is substantially higher than the critical t-table value of 1.699. This indicates a statistically significant difference between the two groups, and H_0 was thus rejected. The finding implies that students in the experimental group—who were taught using the 6E-IM with GeoGebra support—demonstrated significantly better visual-spatial ability compared to those in the control group, and their average score met the minimum criteria for learning mastery.

To further assess the instructional effectiveness, a classical completeness test was conducted to evaluate the proportion of students in the experimental class who met the minimum learning completeness criteria. According to the z-test results, z_{count} was 1.898, exceeding the z_{table} value of 1.645. This statistical outcome led to the rejection of H_0, indicating that more than 75% of the students in the experimental group reached the Minimum Mastery Criteria (MMC). This reflects a successful attainment of classical completeness.

The difference in average performance between the two groups was also tested through an independent t_{test}. The result showed a t_{count} of 3.56, which again surpassed the critical value of 1.67. Therefore, the null hypothesis was rejected, confirming that the average visual-spatial ability score of students in the experimental group was significantly higher than that of the control group. This supports the conclusion that the 6E-IM model, when enhanced with dynamic software like GeoGebra, has a favorable effect on students' cognitive performance in visual-spatial tasks.

A further proportion difference test was conducted to determine if there was a significant difference in the number of students achieving mastery between the two groups. The result showed z_{count} = 3.773, which was greater than z_{table} = 1.645. This finding also led to the rejection of H_0, confirming that the proportion of students achieving mastery in the experimental group was significantly higher than that in the control group.

To examine the increase in students' visual-spatial ability before and after the implementation of the 6E-IM with GeoGebra, paired sample tests were conducted using pre-test and post-test scores. The SPSS output revealed a p-value of 0.000, which is below the 0.05 threshold. Hence, H_0 was rejected, suggesting that the post-test scores were significantly higher than the pre-test scores. This indicates that the 6E-IM model with GeoGebra effectively improved students' visual-spatial ability over the course of the intervention.

In addition to the significance testing, the magnitude of improvement was evaluated using gain score analysis. The normalized gain obtained was 9.91%, which falls within the 31%–70% interval, indicating a moderate level of improvement. This suggests that although the gains were not drastic, the 6E-IM model had a substantial and measurable impact on the development of students' visual-spatial capabilities.

To determine the influence of the instructional model as a whole, a regression analysis was conducted using students' responses from the visual-spatial ability questionnaire and their post-test scores. The significance level was found to be 0.022, which is less than 0.05. This result indicates a statistically significant relationship between the instructional model (as an independent variable) and students' visual-spatial ability (as the dependent variable), thereby confirming that the 6E-IM assisted by GeoGebra has a positive and significant effect on student learning outcomes.

Overall, these findings support the assertion that the 6E Instructional Model, especially when integrated with educational technology tools like GeoGebra, is highly effective in fostering students' visual-spatial abilities. As proposed by Bybee et al. (2006), the 6E-IM promotes active student engagement, inquiry-based learning, and deeper conceptual understanding. When applied to mathematical contexts, this model enables students to visualize abstract concepts more concretely, especially when supported by dynamic visual aids like GeoGebra. Therefore, the implementation of the 6E-IM model in mathematics education holds great potential to enhance students' spatial reasoning and cognitive performance, as corroborated by both quantitative data and educational theory.

3.2 Discussion

The validation results of the developed instructional materials and research instruments—comprising the teaching module, student worksheets, pre-test and post-test instruments, observation sheets, visual-spatial ability questionnaire, and interview guidelines—showed that all instruments attained a "very good" category of validity, as assessed by expert validators. This indicates that the materials are feasible for implementation and can adequately support the research objectives. Instrument validity is a critical component in educational research, as emphasized by Fraenkel, Wallen, & Hyun (2012), who noted that the quality of data is directly influenced by the reliability and validity of the tools used for data collection.

During the implementation phase, the application of the 6E-IM assisted by GeoGebra was observed to be effective and aligned closely with the instructional design as outlined in the teaching module. Each phase of the 6E-IM—Engage, Explore, Explain, Elaborate, Evaluate, and Extend—was implemented systematically, offering students structured opportunities to engage actively and develop conceptual understanding. This process is in line with constructivist learning theory, which posits that learners build knowledge through experience and interaction, as proposed by Piaget and Vygotsky (in Slavin, 2005).

The findings of this study are in line with previous research conducted by Sudirman et al (2022), study found that both geometry self-efficacy and the instructional model (6E-IM integrated with AR vs. standard 6E-IM) significantly influenced students' 3D geometry thinking skills, with effect contributions of 20.5% and 16.2%, respectively. These findings support the notion that student-centered instructional models enhanced by technology significantly contribute to the development of students' higher-order thinking skills. Similar conclusions were drawn by Çekmez (2020) who asserted that technological tools such as AR and dynamic mathematics software can meaningfully improve students' spatial reasoning.

In the current study, the integration of GeoGebra into the 6E-IM provided meaningful support for students in solving contextual mathematical problems and in deepening their understanding of abstract mathematical concepts, particularly visual-spatial tasks. GeoGebra served as an interactive and dynamic tool for visualizing mathematical concepts, making abstract ideas more accessible and fostering exploratory learning. This aligns with the work of Zulnaidi et al. (2020), who demonstrated that

GeoGebra helps bridge the gap between abstract mathematics and visual representation, making it easier for students to grasp complex ideas.

Statistical analysis further substantiates these findings. The results of Hypothesis Test III revealed that students who were taught using the 6E-IM model assisted by GeoGebra scored significantly higher in visual-spatial ability compared to those taught with the standard 6E-IM model. The significance value obtained (Sig. = 0.022 < 0.05) confirms that the integration of GeoGebra had a positive and statistically significant effect on students' visual-spatial skills. This finding is corroborated by the study of Nuratifa et al. (2024), which found significant gains in students' mathematical representation skills following the integration of GeoGebra into instruction. Their study reported an N-gain of 0.72—indicating moderate improvement—and an effect size of 2.75, which signifies a very high impact on learning outcomes. The average test scores increased from 31.6 (pre-test) to 81.16 (post-test), reinforcing the effectiveness of GeoGebra in supporting mathematical visualization and conceptual learning.

Further supporting evidence comes from the research of Setyawan et al (2024), who found that GeoGebra-enhanced problem-based learning not only improved students' conceptual understanding but also developed their mathematical representation and spatial reasoning abilities. Similarly, Kusumah et al. (2020) reported that the use of GeoGebra in geometry learning significantly improved students' ability in spatial rotation and visual imagination.

Taken together, these results confirm that the integration of GeoGebra within the structured 6E-IM framework yields substantial educational benefits. Students become active learners who engage in problem-solving and reflective thinking, while teachers act as facilitators. The structured tasks in the LKPD help guide students through the cognitive processes necessary for analyzing and solving mathematical problems using spatial reasoning. The synergy between the pedagogical structure of the 6E-IM and the dynamic visual features of GeoGebra presents a powerful approach for enhancing spatial reasoning, fostering student engagement, and improving learning outcomes in mathematics education.

4. Conclusion

The findings of this study unequivocally demonstrate that the 6E-IM integrated with GeoGebra constitutes a highly effective and innovative approach for enhancing students' mathematical visual-spatial abilities, particularly within the context of prism geometry. The rigorously validated learning materials and instruments, combined with consistent positive observations during implementation, confirm that this blended pedagogical model not only meets high-quality standards but also significantly elevates students' capacity to engage with and solve spatial problems. The statistically significant positive impact of GeoGebra integration underscores the transformative potential of dynamic, technology-enhanced inquiry learning frameworks in fostering deeper conceptual understanding and spatial reasoning skills. These results advocate for the broad dissemination and adoption of GeoGebra-assisted instructional materials, empowering educators to leverage this powerful synergy of technology and pedagogy to cultivate advanced spatial competencies critical for mathematical proficiency and STEM learning. In sum, this study positions the GeoGebra-supported 6E-IM as a forward-thinking, evidence-based model that meaningfully advances mathematics education by bridging abstract concepts with tangible, interactive learning experiences.

The results of this study have important implications for mathematics education, particularly in the development of instructional models that effectively integrate technology to enhance higher-order cognitive skills such as visual-spatial ability. The success of the GeoGebra-assisted 6E Instructional Model suggests that educators should consider adopting dynamic digital tools within structured inquiry-based learning frameworks to promote active student engagement and deeper conceptual understanding. This approach not only supports students in mastering complex spatial concepts but also prepares them for future STEM-related learning by fostering critical thinking and problem-solving skills. Furthermore, curriculum developers and educational policymakers are encouraged to facilitate the integration of such technology-enhanced models into formal teaching practices, providing adequate training and resources to maximize their benefits in diverse classroom settings.

Despite the promising outcomes, this study has several limitations that should be acknowledged. First, the research was conducted within a specific content area—prism geometry—and the findings may not be directly generalizable to other mathematical topics or subjects without further validation. Second, the sample size and the context of the study, which was limited to a particular educational level and geographic area, may restrict the broader applicability of the results. Additionally, while GeoGebra integration showed significant positive effects, the study did not explore long-term retention of visual-spatial skills or the potential challenges teachers face in implementing this model effectively. Future research should address these limitations by expanding the scope to different mathematical domains, including longitudinal studies to assess sustained impacts, and investigating teacher readiness and support mechanisms necessary for successful technology integration.

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Conflict of Interest
The authors declare no conflict of interest.

5. References

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