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Abstract

This study aims to test the effectiveness of GeoGebra Augmented Reality in improving students' mathematical problem-solving skills. The method used is a quasi-experiment with a posttest-only control group design. The research population is students of the Mathematics Education Study Program at a private university in Indonesia, with a sample of 32 students selected using random sampling techniques (17 students in the experimental group and 15 students in the control group). The study was conducted for 5 weeks with a duration of 2.5 hours per week. Data were collected through mathematical problem-solving tests and analyzed using normality tests (Kolmogorov-Smirnov and Shapiro-Wilk), homogeneity tests (Levene's Test), and independent t-tests after meeting the prerequisites of parametric analysis. The results showed that there was a significant difference between the experimental group using GeoGebra Augmented Reality and the control group using conventional methods ($t = 3.790$, $p < 0.05$, Cohen's $d = 1.02$), with the experimental group experiencing a significant improvement in mathematical problem-solving ability. These results indicate that the application of Augmented Reality technology in mathematics learning can be an effective innovation in improving students' problem-solving skills.

Introduction

The ability to solve mathematical problems is an essential skill that must be possessed by Mathematics Education students (Al-Khateeb, 2018; Lubis, 2021; Nugroho, 2019). These skills are not only important in an academic context, but also in everyday life and the increasingly complex world of work (Megawati, 2020; Wangid, 2021). Therefore, innovations are needed in learning methods to improve students' mathematical problem-solving skills. In recent decades, technology has played a crucial role in supporting mathematics education (Akin et al., 2025; Gusteti et al., 2021, 2024). One of the most widely used software applications in mathematics learning is GeoGebra. GeoGebra is an interactive software that integrates various mathematical representations, such as algebra, geometry, statistics, and calculus, enabling students to explore mathematical concepts dynamically and visually (Bedada, 2022; Bueno et al., 2021; Çekmez, 2023; Jelatu, 2018; Kholid, 2022; Kusumah, 2020). With its flexible features, GeoGebra can be utilized both for independent learning and in classroom settings to help students comprehend abstract concepts through more concrete visualizations (Birgin & Acar, 2020; Iparraguirre-Villanueva et al., 2024; Ishartono, 2022b, 2022a; Juandi, 2021).

With technological advancements, GeoGebra has evolved into an Augmented Reality (AR)-based version, known as GeoGebra AR. This technology allows the visualization of mathematical concepts in a three-dimensional environment, offering a more interactive and immersive learning experience (Trappmair & Hohenwarter, 2019; Widada et al., 2021). GeoGebra AR enables students to observe mathematical objects in 3D, manipulate them, rotate them, and explore them from different perspectives. This provides a deeper learning experience compared to traditional two-dimensional approaches (Budinski & Lavicza, 2019; Iparraguirre-Villanueva et al., 2024).

The primary advantage of GeoGebra AR lies in its ability to enhance the understanding of abstract mathematical concepts. In mathematics, many concepts are difficult to grasp solely through symbolic representations or two-dimensional graphs, such as solid geometry, three-dimensional vectors, parametric functions, and quadratic surfaces (Huan et al., 2022). GeoGebra AR allows students not only to visualize but also to interact directly with these representations, supporting an exploration-based and experience-driven learning approach (Jacinto, 2017; Saputra & Fahrizal, 2019).

Additionally, GeoGebra AR can also improve students' mathematical problem-solving skills (Mukhtar et al., 2021). By directly manipulating mathematical objects, students can experiment with different approaches to solving problems, visually test their hypotheses, and develop a more intuitive understanding of the relationships between various mathematical elements. This process aligns with the principles of constructivist learning, which suggests that learning is more effective when students actively construct their understanding through exploration and direct interaction with the material (Lagrimas & Buenaventura, 2023).

Previous studies have demonstrated that Augmented Reality-based technology can enhance students' conceptual understanding and motivation in mathematics learning (Ahmad & Junaini, 2020; Angraini et al., 2023; Bulut & Ferri, 2023; Chen, 2019; Kellems, 2019; Mohammed Jabar et al., n.d.; Paulo et al., 2021; Rahman & Setyaningrum, 2022; Trappmair & Hohenwarter, 2019). However, research specifically examining the effectiveness of GeoGebra AR in improving mathematical problem-solving abilities remains limited. Therefore, this study aims to evaluate the effectiveness of GeoGebra AR compared to conventional methods in enhancing students' problem-solving skills in mathematics education.

Method

This study uses a quasi-experimental method with a posttest-only control group design, which is used to measure the effectiveness of an intervention in conditions where pretest cannot be carried out (Abdalla et al., 2018; Chambrier, 2021; Ferráns, 2022; Jackson, 2009; Larner, 2014). This design allows comparisons between the experimental group that received the treatment and the control group that did not receive the treatment, with the measurement of the results performed after the intervention was given.

In this design, there are two groups that are given different treatments, but measurements are only made after the treatment is given (*posttest*). Here is the experiment design schema used:

Table 1. Research Design

Group	**Treatment**	**Posttest**
Experimental	GeoGebra AR	Final Test
Control	Conventional Methods	Final Test

The research population consisted of students of the Mathematics Education Study Program at one of the private universities in Indonesia. The sample was selected using a random sampling technique, consisting of 32 students (17 experiments, 15 controls) who had completed certain courses relevant to this study. This technique ensures that every individual in the population has an equal chance of being selected, thus increasing the external validity of the research.

The research was conducted for 5 weeks with a learning duration of 2.5 hours per week. The experimental group received learning using GeoGebra Augmented Reality (AR), which allows students to visualize mathematical concepts in a more interactive way. Meanwhile, the control group received learning with conventional methods, such as lectures and material presentations without the help of AR technology. After the treatment was given, both groups underwent a final test (posttest) to evaluate the extent of improvement in students' mathematical problem-solving skills.

This design was chosen because it allows direct comparison between the experimental and control groups without the influence of the pretest, thus reducing the learning effect of the initial measurement. In addition, the use of posttest-only helps ensure that the results obtained are really the impact of the treatment given, not the result of other factors such as the exercise effect of the previous test (Qin et al., 2019). The instrument used in this study is in the form of a mathematical problem-solving ability test, which has been tested for content validity by three mathematics education experts and has a reliability of $\alpha = 0.85$ based on Cronbach's Alpha test.

Data Analysis Techniques

1. Normality Test: Kolmogorov-Smirnov and Shapiro-Wilk to ensure that the data from both groups were normally distributed.
2. Homogeneity Test: Levene's Test to ensure that the variance of the data of the two groups is homogeneous before inferential statistical analysis is performed.
3. Hypothesis Test: An independent t-test to compare the mean posttest score between the experimental group and the control group to see if there is a significant difference.
4. Effect Size: Cohen's d to measure the strength of the influence of GeoGebra AR in improving mathematical problem-solving ability.

The results of the analysis were interpreted based on the significance value (p-value), where if the $p\text{-value} < 0.05$, then there was a significant difference between the two groups.

Results

To test the effectiveness of GeoGebra *Augmented Reality* in improving students' mathematical problem-solving skills, a series of statistical analyses were conducted. This analysis includes normality tests, homogeneity tests, and independent t-tests to ensure the validity of the research results. The normality test was performed to determine whether the data from both groups (experimental and control) were normally distributed, which is an important assumption in parametric analysis. The homogeneity test was used to determine whether the two groups had the same variance, so that statistical analysis could be carried out more accurately. An independent t-test was used to test whether there was a significant difference between the experimental and control groups after the treatment was administered.

The following are the results of the statistical analysis obtained:

Normality Test

The normality test was performed to ensure that the data from both groups followed the normal distribution, which is one of the assumptions in the independent t-test. Normality was tested using two methods, namely Kolmogorov-Smirnov and Shapiro-Wilk, with the following results:

Table 2. Normality Test

Group	Kolmogorov-Smirnov (p)	Shapiro-Wilk (p)
Experimental	0.165	0.923
Control	0.106	0.965

The criterion for determining whether the data is normally distributed is that if the p-value > 0.05, then the data is considered to follow the normal distribution (Field, 2018). Based on the results above, the p-values for both groups are greater than 0.05, indicating that the data from both the experimental and control groups are normally distributed.

Homogeneity Test

The homogeneity test was conducted to determine whether the variance of the two groups was equal, which is a prerequisite for performing an independent t-test. This test used Levene’s Test, with the following results:

Table 3. Homogeneity Test

Levene’s Test	F	Sig.
Variance Score	0.103	0.749

The criterion in the homogeneity test is that if the value of Sig. > 0.05, then the variance of the two groups is considered homogeneous (Pallant, 2020). In this result, the significance value is 0.749, which is greater than 0.05, so it can be concluded that the variance of the two groups is homogeneous. This means that both groups have a similar level of data dispersion, so the t-test can be performed without the need for additional correction.

Hypothesis Test (Independent t-Test)

An independent t-test was used to test whether there was a significant difference between the experimental group using GeoGebra Augmented Reality and the control group using conventional methods of learning. The t-test results are shown in the following table:

Table 4. t Test Results

Group	**Average Posttest**	**SD**	***t***	***df***	***p-value***
Experimental	75.42	9.76	3.790	30	0.000
Control	60.56	7.94			

Table 4 presents the results of an independent t-test analysis conducted to compare posttest scores between the experimental group using GeoGebra Augmented Reality (AR) and the control group using conventional learning methods. The results of the analysis showed that the experimental group had an average posttest score of 75.42 with a standard deviation of 9.76, while the control group obtained an average of 60.56 with a standard deviation of 7.94. This difference indicates that students who study with GeoGebra AR have a better understanding and ability to solve mathematical problems compared to students who use conventional methods. The results of the statistical test showed that the value of $t = 3.790$ with degrees of freedom (df) = 30, and the value of p-value = 0.000. With a p < of 0.05, it can be concluded that there is a statistically significant difference between the experimental group and the control group.

This shows that students who study with GeoGebra AR have a better understanding and mathematical problem-solving ability compared to students who use conventional methods. These findings confirm that the use of GeoGebra AR in mathematics learning, especially in spatial geometry materials, can increase the effectiveness of learning and help students understand concepts in a more interactive way. Thus, this research supports the integration of Augmented Reality (AR) technology in mathematics education as an innovative approach to improve students' problem-solving skills.

Thus, it can be concluded that students who learn using GeoGebra Augmented Reality have significantly improved their mathematical problem-solving skills compared to students who use conventional methods. These results support the hypothesis that technology-based learning can improve effectiveness in understanding and solving mathematical problems.

Effect Size Calculation (Cohen's d)

The effect size is used to determine the strength of an intervention's impact by comparing the mean difference between the experimental and control groups while considering the pooled standard deviation of both groups. This calculation is essential for understanding the practical significance of the research findings, beyond solely relying on inferential statistical tests (Lakens, 2013; Larner, 2014).

Table 5. Cohen’s d Interpretation Categories

Cohen’s d Range	Effect Size Category
0.2 – 0.49	Small effect
0.5 – 0.79	Medium effect
≥ 0.8	Large effect

The following are the results of the effect size calculation based on data from the experimental group and the control group:

Tabel 6. Effect Size (Cohen’s d)

Group	Average Posttest	Standard Deviation (SD)	n	Effect Size (Cohen’s d)
Experimental	75.42	9.76	17	**1.02**
Control	60.56	7.94	15	-

Table 6 shows that the average posttest of the experimental group using GeoGebra AR is higher than that of the control group, which is 75.42 compared to 60.56. The standard deviation in the experimental group was slightly greater (9.76) than in the control group (7.94), indicating a wider variation in scores in the experimental group. With a sample of 17 people in the experimental group and 15 people in the control group, the effect size obtained was 1.02.

Based on Cohen's interpretation, Cohen's d score of 1.02 is included in the large effect category, which shows that the use of GeoGebra AR has a strong impact on improving students' problem-solving skills compared to the learning methods used in the control group. These results indicate that GeoGebra AR can be an effective learning tool in supporting the improvement of students' understanding and skills in solving problems.

Discussion

The results showed that the experimental group using GeoGebra Augmented Reality (AR) experienced a more significant improvement in mathematical problem-solving ability compared to the control group using conventional methods. This shows that the application of GeoGebra AR in learning spatial geometry provides real benefits for students in understanding complex geometric concepts. These findings are in line with previous research that shows that Augmented Reality (AR) can increase student interactivity and involvement in the learning process (Alzahrani, 2020; Gargrish, 2021; Gopakumar et al., 2024; Lima et al., 2020; Özçakır, 2022; Rebollo et al., 2022; Tan et al., 2023; Uriarte-Portillo et al., 2023). GeoGebra AR allows students to explore the shape and properties of building spaces visually and interactively, which cannot be done optimally in conventional learning methods.

Integration of GeoGebra AR in Spatial Geometry Learning

Exploration of 3D Geometry Models in GeoGebra AR

One of the main challenges in studying spatial geometry is the difficulty in abstracting the shape and properties of space construction. With GeoGebra AR, students can directly see three-dimensional models of space structures such as cubes, blocks, prisms, pyramids, tubes, cones, and spheres in a more realistic view.

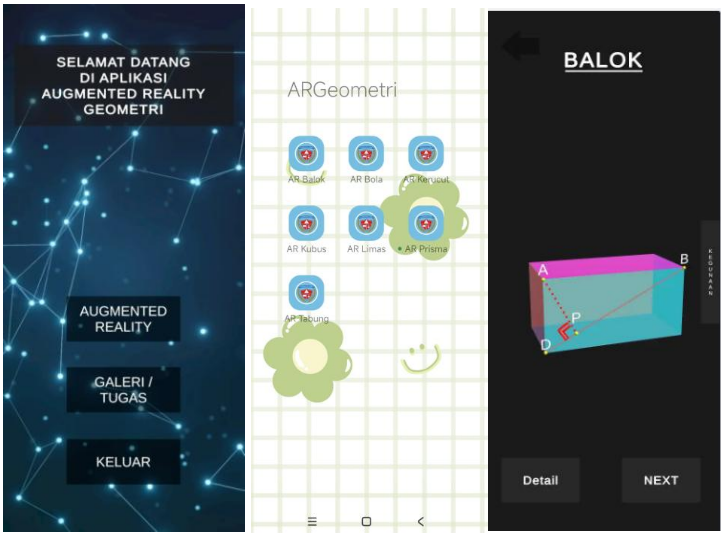

Figure 1. AR Geometry Application on a Tablet Device

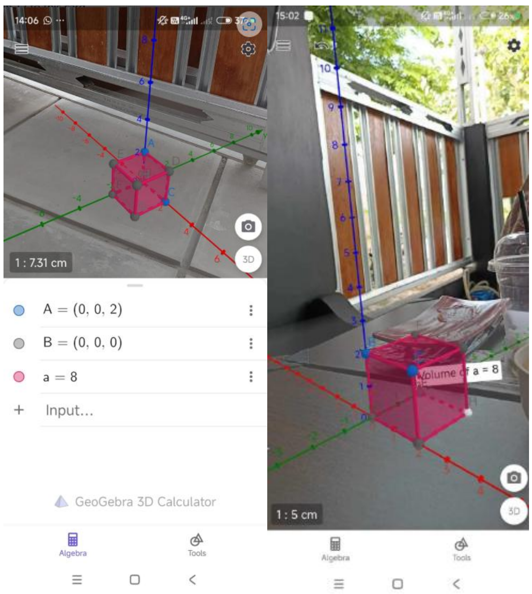

Figure 2. Students Manipulate a 3D Geometric Model using the GeoGebra AR Application on a Tablet Device.

In this activity, students can:

a. Rotate and zoom in on the building space to understand its shape from different perspectives.
b. Observing how the construct of space is formed from its basic elements such as points, lines, and planes.
c. Analyze the relationships between the building parts of a space, such as the number of sides, ribs, and

corner points.

Simulation of Spatial Construction Nets

Understanding spatial construction nets is often a challenge for students because it requires good spatial visualization skills. With **GeoGebra AR,** students can simulate the **building nets of spaces** that can be opened and closed in three dimensions directly.

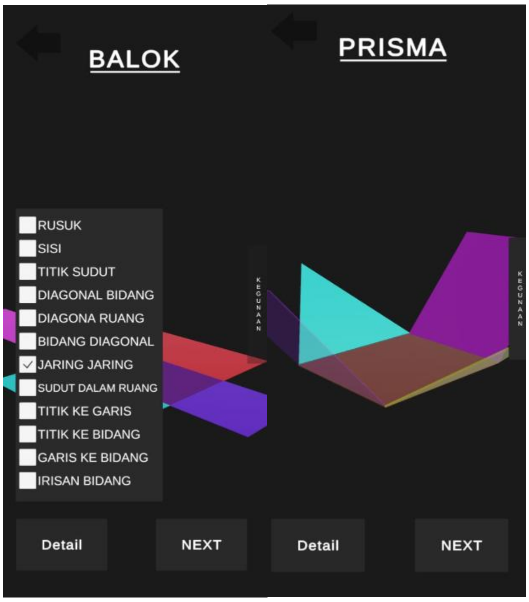

Figure 3. Prism Meshes in AR Geometry Applications

The benefits of this activity are:

a. Students can understand how a space building is formed from its nets.
b. Students can predict the shape of the nets from various space structures before seeing the simulation results.
c. It is easier for students to associate the concept of nets with the volume and surface area of the space.

Research Implications

The results of this study have important implications in the field of mathematics education, especially in learning spatial geometry. There are several recommendations that can be taken from this study:

1. Integration of GeoGebra AR in Mathematics Education Curriculum: The use of Augmented Reality technology in mathematics learning needs to be introduced in the curriculum to improve students' spatial visualization skills.
2. Development of Interactive Teaching Materials: Lecturers can develop teaching materials based on GeoGebra AR to help students understand the concepts of spatial geometry more effectively.
3. Training for Lecturers and Students: To optimize the use of GeoGebra AR, it is necessary to have training for lecturers and students in operating the application and integrating it into learning.

4. Advanced Research: Further studies can explore the application of GeoGebra AR in more complex spatial geometry concepts or in other learning contexts, such as physics and civil engineering.

Conclusion

This study found that the use of GeoGebra Augmented Reality (AR) significantly improved students' mathematical problem-solving skills compared to conventional learning methods. The integration of AR technology in mathematics education enhances learning quality, particularly in spatial geometry, by providing interactive features and three-dimensional visualization. These features enable students to explore spatial constructions more intuitively, understand geometric nets, analyze volume and surface area, and simulate geometric transformations in space. Additionally, the use of GeoGebra AR fosters higher motivation and active engagement, making the learning process more dynamic and interactive. However, despite its positive impact, the implementation of this technology requires adequate infrastructure, human resource readiness, and systematic curriculum integration to maximize its benefits.

Recommendations

To optimize the use of GeoGebra AR in mathematics education, several measures should be taken. First, the application of GeoGebra AR should be expanded to various mathematics courses, particularly those that involve abstract concepts requiring three-dimensional visualization, such as analytical geometry and calculus. This expansion can help students develop a deeper understanding of complex mathematical structures. Second, long-term studies should be conducted to assess the sustained impact of GeoGebra AR on students' concept retention, problem-solving skills, and overall learning outcomes. Understanding its effectiveness over time will provide valuable insights for educators and researchers.

Furthermore, training programs for both lecturers and students should be introduced to ensure that they are equipped with the necessary skills to integrate this technology effectively into the learning process. Alongside training, the development of AR-based teaching materials that align with students' needs should be prioritized, allowing for more systematic integration into formal education. Lastly, comparative studies with other technology-based learning methods, such as Virtual Reality (VR) and Artificial Intelligence (AI)-based simulations, should be conducted to evaluate their effectiveness in enhancing conceptual understanding and student engagement in mathematics. By implementing these strategies, the use of GeoGebra AR can be further optimized, ensuring its long-term contribution to improving mathematics education at the university level.

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