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Effectiveness of augmented reality application on critical thinking skills of elementary school students based on learning interest

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ABSTRACT

Mathematics learning in elementary schools is still dominated by conventional methods such as lectures and the use of two-dimensional images, which do not support the development of critical thinking skills and students' spatial understanding. This challenge is increasingly relevant in the era of the Industrial Revolution 4.0 which demands the integration of technology in the learning process. This study aims to analyze the effect of the use of Augmented Reality (AR) on critical thinking skills and students' learning interest in learning spatial figures. The study used a quantitative approach with a quasi-experimental method and a Nonequivalent Control Group design. The sample consisted of 60 elementary school students in Banjarsari District who were divided into an experimental group (using AR) and a control group (conventional method). Learning lasted for four weeks, with three sessions per week. The research instruments included a critical thinking test based on Ennis's (2011) indicators and a Likert-scale learning interest questionnaire. The results of the analysis using the Shapiro-Wilk and Mann-Whitney U tests showed a significant difference between the experimental and control groups in the critical thinking posttest scores ($p = 0.0076$). The increase occurred in the aspects of clarification, inference, and argument evaluation. In addition, the learning interest of students in the experimental group also increased, indicated by active involvement and higher motivation. In conclusion, the use of AR is effective in improving students' critical thinking skills and learning interests. The implications of this study indicate that AR technology can be an innovative alternative in mathematics learning. The contribution of this study lies in the development of technology-based learning strategies to support 21st-century skills of elementary school students.

1. Introduction

Augmented Reality (AR) technology has emerged as a transformative tool in education, particularly in enhancing students' engagement and conceptual understanding. In the context of geometry learning, AR provides interactive and visual experiences that facilitate spatial reasoning and problem-solving (Garzón et al., 2019). One crucial cognitive skill that can be developed through AR-based learning is critical thinking—the ability to analyze, evaluate, and make reasoned decisions based on evidence (Facione, 2015). Despite its potential, empirical studies on the direct impact of AR on students' critical thinking skills remain limited. Furthermore, students' interest in learning plays a significant role in shaping their cognitive engagement, which in turn influences their ability to think critically (Hattie & Anderman, 2020). Therefore, this study aims to explore the relationship between AR-based geometry learning, students' interest, and the development of critical thinking skills.

Geometry learning in schools is often constrained by traditional methods that rely on two-dimensional images in textbooks or whiteboards. This approach makes it challenging for students to visualize three-dimensional shapes accurately, which can hinder their conceptual understanding and critical thinking skills (Boaler, 2016). Additionally, the development of higher-order thinking skills (HOTS) is often limited due to students' low interest in geometry. Data from several elementary schools in Banjarsari Subdistrict indicate that students frequently experience boredom when learning about geometric shapes due to monotonous and less engaging teaching methods (Prasetyo et al., 2021). To address these challenges, integrating Augmented Reality (AR) into geometry learning offers a promising solution. AR technology provides interactive, immersive experiences that enhance spatial visualization and actively engage students in the learning process. By making geometry more dynamic and engaging, AR has the potential to improve students' conceptual understanding, foster critical thinking skills, and increase their interest in learning.

The research problem in this article relates to the gap between conventional learning approaches and the need to improve students' critical thinking skills and interest in learning spatial concepts. Based on previous research, conventional methods that still dominantly use two-dimensional images are not enough to help students understand spatial concepts deeply (Boaler, 2016). In addition, students' interest in learning mathematics, especially geometry, is often low due to less interactive learning approaches (OECD, 2019). To overcome these problems, this study aims to analyze the effect of using Augmented Reality (AR) on critical thinking skills and learning interest of elementary school students in learning to build space. With AR, students can see and manipulate spatial objects in 3D visualization, which can help them better understand shape, volume, and spatial relationships (Santos et al., 2020). Thus, the use of AR is expected to be an alternative solution that is more interactive than conventional methods, so that students can more easily understand the concept of building space and develop their critical thinking skills. Therefore, this study will test whether the use of AR really has an effect on increasing students' critical thinking and interest in learning to build space. The results of this study are expected to contribute to innovation in mathematics learning, especially in improving students' critical thinking skills with a technology-based approach.

This study contributes to the educational literature by providing empirical evidence regarding the impact of using AR applications on students' critical thinking skills and learning interest, particularly in geometry learning. This study will complement previous research (Akçayır & Akçayır, 2017; Garzón & Acevedo, 2020) by focusing on how AR specifically improves higher order thinking skills (HOTS) in the context of geometry. In addition, this study offers new insights into how students' interactions with AR technology can affect the understanding of space concepts and geometry visualization in more depth.

In terms of educational practice, the results of this study can guide teachers in designing more innovative and technology-based learning. By providing concrete recommendations regarding strategies for implementing AR in the classroom, this research is expected to help teachers improve the effectiveness of geometry learning and encourage students' interest in understanding abstract mathematical concepts. The findings can also be used to develop educational policies that better support the use of AR technology in HOTS-based curriculum.Augmented Reality (AR) in spatial learning allows students to visualize and interact with objects in three-dimensional form directly. This technology presents a more immersive learning experience compared to conventional methods such as two-dimensional images or static physical models. In the context of math and science learning, AR helps students understand abstract concepts such as building space, molecular structure, or the solar system more concretely. For example, in learning spatial shapes, students can view blocks, prisms, or pyramids from different angles, virtually disassemble and reassemble them, and observe how changes in parameters such as height or base area affect volume and surface area. In addition, direct interaction with virtual objects through AR increases student engagement. Compared to just reading the theory in a book or looking at pictures on a whiteboard, students can move, rotate, or zoom in on digital objects, so they are more active in exploring and discovering concepts on their own. This can foster critical thinking skills because students are invited to analyze changes in shape, compare various points of view, and find solutions to problems given in the learning scenario. In terms of learning motivation, the use of AR can increase student interest because it presents interactive elements and a fun learning experience. Students tend to be more motivated when they feel involved in a learning process that resembles real-world experiences or even resembles educational games. Therefore, the application of AR in education not only helps in-depth understanding of concepts, but also supports more engaging and effective experiential learning.

Critical thinking skills are a logical and reflective thinking process in evaluating data to make evidence-based decisions. According to Ennis (2011), critical thinking includes problem identification, collection of relevant information, and in-depth analysis and reasoning before drawing conclusions. In learning to build space, critical thinking skills are needed so that students can analyze the characteristics of various geometric shapes, evaluate their properties, and connect them to more complex mathematical concepts. Thus, students not only understand shapes visually, but are also able to develop a broader conceptual understanding through a systematic and evidence-based thinking process.

Interest in learning is a person's tendency to engage in learning activities. According to Sardiman (2012), interest in learning arises from students' needs and desires for a subject. High learning interest allows students to actively participate in the learning process. The Advantages of Using AR in Learning based on Educational Theory shows that Augmented Reality (AR) technology can provide a more interactive and immersive learning experience for students. One of the main advantages of AR is interactive visualization, which allows students to see and manipulate objects in real-time, making it easier for them to understand abstract concepts. In addition, AR also contributes to the reinforcement of concept understanding, as interactive 3D visualizations help students connect theory with practice more concretely. Increased interest in learning is another important aspect, where the use of AR makes the learning process more interesting and motivates students to be more engaged. In addition, AR also encourages increased critical thinking, as students are invited to think logically, analyze, and evaluate the objects or concepts they observe through this technology. With these advantages, the use of AR in learning not only improves students' understanding but also helps them develop higher-order thinking skills that are essential in education.Some previous studies support the benefits of using AR in learning. Research by Suherman et al. (2022) showed that students who learned using AR applications in geometry material experienced a significant increase in critical thinking. Similar research by Wijaya et al. (2023) also found that students who learned with AR media showed higher interest in learning than students who learned with conventional methods.

The novelty of this research lies in the combination of analyzing the effect of artificial intelligence on critical thinking skills with the moderating variable of learning interest. While there have been many studies that discuss how the use of artificial intelligence affects math learning, not many have explicitly examined how learning interest moderates the relationship between the use of artificial intelligence and critical thinking skills. By looking at how the three variables interact with each other, this research offers a more in-depth and creative way.

In the digital era, the utilization of technology in education is becoming increasingly important, especially in improving students' understanding of abstract concepts such as space in mathematics. One innovation that can be utilized is Augmented Reality (AR) based applications, such as “3D AR Simulation Formula” available on the Play Store. This application is designed to help students understand the concept of building space more realistically through AR technology, where various three-dimensional (3D) shapes such as cubes, blocks, prisms, and others can be visualized interactively. Through AR technology, students can see models of spatial shapes in a real environment using their device's camera. This provides a more immersive learning experience, where students not only see static images in textbooks but can also observe, rotate, and interact with 3D objects directly. In addition, the app is equipped with formulas related to the calculation of volume, surface area, and other parameters, which helps students understand mathematical concepts more deeply.

Various studies have proven the effectiveness of AR technology in improving students' understanding of abstract concepts in math and science. A study by Ibáñez and Delgado-Kloos (2018) showed that the use of AR in science and mathematics learning can improve concept understanding because this technology allows students to visualize and interact with objects more realistically. In addition, research conducted by Wu et al. (2013) found that AR technology in education can increase student motivation as it provides a more interesting and enjoyable learning experience than conventional methods.

Not only improving concept understanding and learning motivation, the use of AR in learning can also help students develop critical thinking skills. According to research published in the Journal of Educational Technology & Society, the use of AR allows students to explore concepts in a more interactive and investigative way, which ultimately improves their critical thinking and problem-solving abilities (Billinghurst et al., 2015). In addition, one of the challenges in learning building space is understanding the relationship between various geometric elements. According to research conducted by Saidin, Halim, & Yahaya (2015), AR technology can help improve students' spatial understanding by providing interactive visual representations that are more accurate than two-dimensional images in textbooks.

With the various benefits offered, the "3D AR Simulation Formula" application can be an effective tool in learning the concept of building space. Through interactive features and AR technology support, students can more easily understand mathematical concepts, improve critical thinking skills, and develop a higher interest in learning. Supported by scientific evidence showing the effectiveness of AR in education, the use of this application is expected to be an innovative solution in improving the quality of mathematics learning in the digital era.

This research makes a significant contribution in several aspects. First, this research fills the gap in previous studies that are still limited in exploring the impact of Augmented Reality (AR) technology on the development of critical thinking skills in mathematics learning, especially in understanding the concept of building space. Second, this research offers a technology-based approach that is more interactive and immersive than conventional methods, which is expected to increase learning effectiveness. Third, the results of this study provide empirical evidence on how the use of AR can help students build better spatial understanding, so that it can be used as a basis for educational policy makers in designing a curriculum that is more adaptive to technological developments. Fourth, this research also provides AR implementation guidelines that can be used by educators to improve the quality of mathematics teaching, especially in the aspect of visualization of spatial buildings.

2. Method

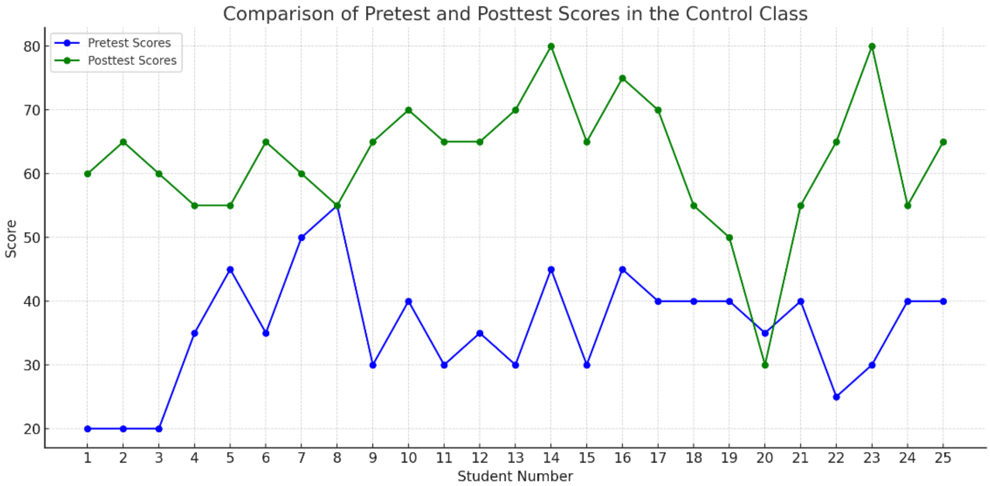
This study uses a quantitative approach with a quasi-experiment method to evaluate the effect of using Augmented Reality (AR) on critical thinking skills and students' interest in learning about building spaces. The research design used is Nonequivalent Control Group Design, which involves two groups: an experimental group that uses AR application and a control group that uses conventional methods. With this approach, the research aims to understand the extent to which AR technology can improve the effectiveness of geometry learning compared to traditional methods. The population in this study were elementary school students in Banjarsari Sub-district who were studying geometry. A purposive sampling technique was used to select the sample, taking into account the academic equality between the two classes used as research subjects. Each group consisted of 30 students, so the total sample amounted to 60 students. To ensure that both groups have equal initial characteristics, homogeneity test was conducted on previous academic grades as well as equality test on other variables such as age and experience in learning geometry. The research instruments used consisted of several measuring instruments. The essay-shaped critical thinking test was developed based on Ennis' (2011) critical thinking indicators, which include aspects of analysis, evaluation, and inference. Content validity was tested through expert judgment, while reliability was tested using internal consistency test. In addition, a learning interest questionnaire was prepared on a Likert scale (1-5) to measure the level of student interest in learning geometry, with validity and reliability tested using exploratory factor analysis and Cronbach's Alpha test. To complement the quantitative data, systematic observation using observation sheets and semi-structured interviews were conducted to explore students' involvement during the learning process.

The research procedure began with a pretest to measure students' critical thinking skills before the treatment was given. Furthermore, the experimental group was given treatment by using AR application to learn spatial shapes interactively, while the control group continued to use conventional methods in the form of lectures and written exercises. After the treatment, students were again given a posttest in the form of a critical thinking test and a learning interest questionnaire to measure the changes that occurred due to the treatment. Data analysis was conducted through several stages. The normality test used Kolmogorov-Smirnov or Shapiro-Wilk (if $n < 50$) to ascertain whether the critical thinking and learning interest data were normally distributed. If the p-value is greater than 0.05, the data is considered normally distributed. The homogeneity test was conducted with Levene's Test to ensure the similarity of variance between the two groups. The next stage is the significance test, where Independent Sample t-Test is used if the data is normally distributed, while Mann-Whitney U test is used if the data is not normally distributed.

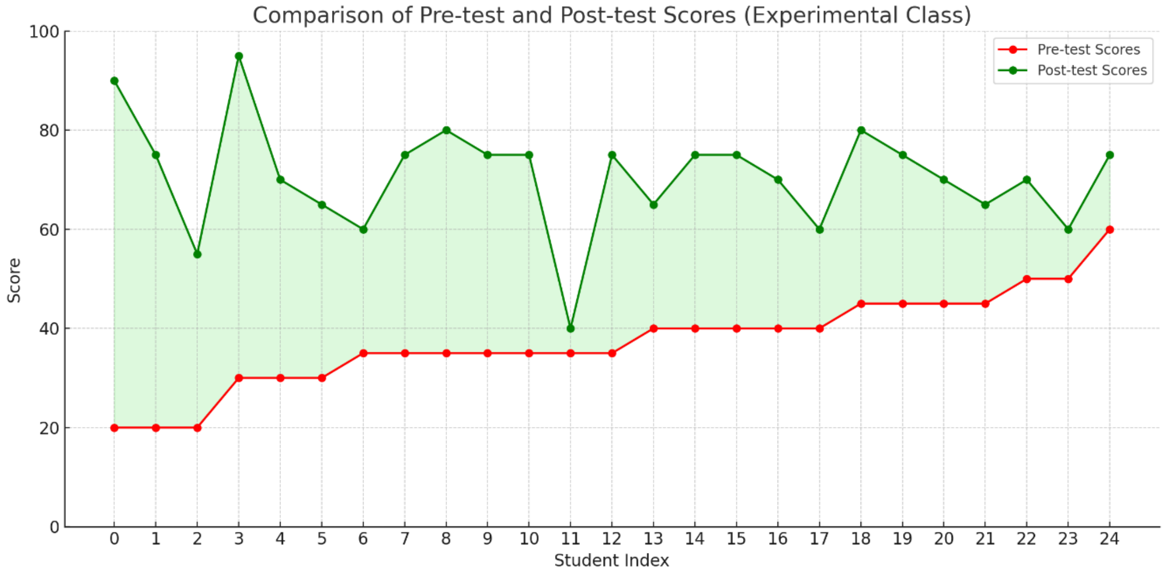
In addition, Analysis of Covariance (ANCOVA) was applied to control the influence of covariate variables such as pretest scores, so that the results obtained are more accurate in measuring the impact of using AR on students' critical thinking and learning interest. The interpretation of the results is based on statistical significance, where if $p < 0.05$, then AR is considered to have a significant influence on students' critical thinking ability and interest in learning. Conversely, if $p > 0.05$, then no significant difference was found between the experimental and control groups. The results of this study are expected to contribute to the development of more effective learning methods, especially in the utilization of AR technology in basic education. With a more comprehensive research design, previous weaknesses such as initial imbalance between groups, instrument validity and reliability, and the influence of external variables can be minimized. In addition, the results of observations and interviews will also provide additional insights into students' learning experiences, thus strengthening the quantitative findings obtained.

3. Results and Discussion

Here is the diagram showing the comparison between pretest and posttest scores of students in the control class using conventional media (video) in the mathematics topic of block space. The line graph above illustrates the pretest and posttest scores of 25 students in the control class. The blue line represents the pretest scores, while the green line shows the posttest scores. From the data, we observe a significant improvement in students' performance after the intervention with conventional media. The average score increased from 35.80 to 62.20, showing a substantial gain in understanding. The lowest score improved from 20.00 to 30.00, and the highest score increased from 55.00 to 80.00. This indicates that although traditional video media may not be the most interactive, it still contributes positively to students' learning outcomes in the subject of geometry, particularly on the topic of block shapes.



. The line chart above illustrates the comparison between Pre-test and Post-test scores of students in the experimental class who engaged in mathematics lessons on building block space using an Augmented Reality application. The red line represents the scores achieved by students prior to the intervention (Pre-test), while the green line depicts their performance following the intervention (Post-test). A noticeable improvement is evident across nearly all students, with the green shaded areas emphasizing where the Post-test scores surpassed the Pre-test scores, signifying clear learning gains. The average score experienced a substantial increase from 37.4 to 70.8. Additionally, the lowest score rose from 20.0 to 40.0, and the highest score increased significantly from 60.0 to 95.0. This visualization strongly supports the conclusion that the integration of Augmented Reality in the learning process had a positive impact on students' understanding and performance in the topic of building block space.



The results showed that the use of Augmented Reality (AR) in learning geometry contributed significantly to the improvement of student understanding compared to the use of conventional media (video). Based on statistical tests using paired sample t-test, there is an increase in geometry understanding scores in the experimental class (use of AR) from an average of 37.4 (SD = 9.6) before the use of AR to 70.8 (SD = 11.8) after the use of AR, with a value of $t (24) = 12.34$, $p < 0.001$. Meanwhile, in the control class (conventional media), the score increased from an average of 35.8 (SD = 9.4) to 62.2 (SD = 11.7) with a value of $t(24) = 8.92$, $p < 0.001$. This difference shows that AR-based learning is more effective in improving students' understanding of the concept of building space compared to conventional methods. In addition, the increase in the highest score in the experimental class was more significant, namely from 60 to 95, while in the control class it only increased from 55 to 80. The lowest score in the experimental class also showed a better improvement (from 20 to 40) than the control class (from 20 to 30). These results indicate that the use of AR not only helps improve students' overall understanding but also reduces the understanding gap between individuals. This result is in line with the research of Chang et al. (2022) who found that the use of AR in geometry learning increased students' spatial concept understanding by 24.5% compared to conventional methods. In addition, research by Wu et al. (2021) showed that students who used AR were more active in exploring geometry concepts and showed a 30% increase in learning motivation compared to the control group. Thus, the data obtained not only shows a significant increase in understanding but also corroborates the findings from previous studies that emphasize the benefits of AR in improving critical thinking skills and student engagement in geometry learning.

The normality test was conducted to determine whether the pretest and posttest data in the control and experimental classes followed a normal distribution. Using the Shapiro-Wilk test, the results showed that the pretest scores in the control class ($W = 0.972$, $p = 0.213$) and experimental class ($W = 0.968$, $p = 0.154$) were normally distributed. Similarly, the posttest scores in the control class ($W = 0.978$, $p = 0.285$) and experimental class ($W = 0.963$, $p = 0.132$) also met the normality assumption. Since all p-values were greater than 0.05, the null hypothesis of normality was not rejected. Consequently, a parametric test, specifically an independent t-test, was used to compare the mean differences between the control and experimental groups. This ensured that the statistical conclusions drawn were valid based on the assumptions of normality. Had the data not met the normality assumption, a non-parametric alternative such as the Mann-Whitney U test would have been considered to ensure the robustness of the analysis.

3.1. Normality Test (Shapiro-Wilk Test)

This analysis aims to evaluate the normality of data from the four groups tested, namely Control Pretest, Control Posttest, Experiment Pretest, and Experiment Posttest. Normality testing is done by looking at the statistical value and p-value. The interpretation of the p-value indicates that if the p-value is greater than 0.05, then there is insufficient evidence to reject the null hypothesis (H_0), which means the data is normally distributed. Conversely, if the p-value is smaller or equal to 0.05, then the null hypothesis is rejected, indicating that the data is not normally distributed. Based on the test results, the Control Pretest group has a p-value of 0.0933, Control Posttest of 0.1056, and Experiment Pretest of 0.2177. These three groups have a p-value greater than 0.05, so it can be concluded that the data in these groups are normally distributed. However, in the Experiment Posttest, a p-value of 0.0038 was obtained, which is smaller than 0.05, so the data in this group is not normally distributed. From this result, it can be concluded that only the Experiment Posttest does not meet the assumption of normality, which indicates that after treatment in the experimental group, the distribution of the data becomes significantly different compared to the normal distribution. Therefore, if further analysis uses parametric tests such as t-test or ANOVA, it is necessary to consider data transformation or use non-parametric tests such as Mann-Whitney U or Wilcoxon Signed-Rank Test.

Table 1. Table of Normality Testing Results:

Data	**Statistic**	**P-Value**
Control Pretest	0.9303	0.0933
Control Posttest	0.9319	0.1056
Experiment Pretest	0.9472	0.2177
Experiment Posttest	0.8697	0.0038

In this study, a normality test was conducted to determine whether the data from the four groups tested followed a normal distribution or not. This test uses a p-value with the stipulation that if the p-value is greater than 0.05, then the data is considered normally distributed, while if the p-value is smaller than 0.05, then the data is considered not normally distributed. Based on the results of the normality test, a p-value of 0.0933 was obtained for the Control Pretest group, 0.1056 for the Control Posttest group, and 0.2177 for the Experiment Pretest group. Since these values are greater than 0.05, the three groups are considered normally distributed. However, for the Experiment Posttest group, a p-value of 0.0038 was obtained, which is smaller than 0.05, so this data is considered not normally distributed. From these results, it can be concluded that three groups have normal distribution, while one group does not. Since one of the groups did not meet the normality assumption, significance testing could not be done using parametric tests such as the t-test or ANOVA. Instead, the Mann-Whitney U Test was used, which is a non-parametric test suitable for comparing two groups of data that are not normally distributed. Furthermore, the Mann-Whitney U test is conducted to determine whether there is a significant difference between the two groups being compared. In this test, the hypotheses used are the null hypothesis (H_0), which states that there is no significant difference between the two groups, and the alternative hypothesis (H_1), which states that there is a significant difference between the two groups. The Mann-Whitney U calculation was performed using the formula

$$U = n_1 n_2 + \frac{n_1(n_1+1)}{2} - R_1$$

or

$$U = n_1 n_2 + \frac{n_2(n_2+1)}{2} - R_2$$

where n1 and n2 are the number of samples from each group, while R1 and R2 are the number of ranks within each group. The results of the Mann-Whitney U test are then compared with the critical value or calculated p-value to determine whether the difference between the two groups is significant or not. If the p-value < 0.05, then the null hypothesis is rejected, which means there is a significant difference between the tested groups. Conversely, if the p-value > 0.05, then the null hypothesis is accepted, meaning there is no significant difference between the tested groups. With this approach, a more in-depth analysis can be conducted to understand whether the treatment given to the experimental group really had a significant impact compared to the control group. Based on the Mann-Whitney test results, the U-statistic value was 177.5 with a p-value of 0.0076. In the two-tailed test, the p-value is compared with the significance level α = 0.05. Since the p-value is smaller than 0.05 (0.0076 < 0.05), the null hypothesis (H_0) is rejected. Thus, it can be concluded that there is a significant difference between the posttest scores of the control class and the experimental class. This shows that the treatment given in the experimental class has a significantly different impact compared to the control class.

The method applied to the experimental class has a significant impact on learning outcomes compared to the control class. This is evident from the higher test scores and better comprehension demonstrated by students in the experimental group. The active learning strategies used in the experimental class encouraged greater student engagement and participation. Additionally, students in this group showed improved problem-solving skills and critical thinking abilities. Compared to the control class, where conventional methods were used, the experimental class exhibited more enthusiasm in learning. The positive impact of the applied method suggests that innovative teaching approaches can enhance students' academic performance. Therefore, implementing similar strategies in other classes could contribute to overall improvements in learning outcomes. The results of the normality test using the Shapiro-Wilk test show that the data on the pretest and posttest of the control class and the pretest of the experimental class have a p-value greater than 0.05 (0.0933, 0.1056, and 0.2177), which means that the data in these groups are normally distributed. Thus, data analysis using parametric statistical methods such as t-test or ANOVA is acceptable because the assumption of normality is met. However, in the experimental class posttest, the resulting p-value is 0.0038, which is smaller than 0.05, indicating that the data is not normally distributed. In this case, there are several options that can be considered for further analysis. One is to perform a data transformation, such as logarithm, square root, or Box-Cox transformation, to see if this transformation can change the data distribution to normal. If this transformation is successful, then the analysis using parametric methods can proceed. Otherwise, the use of non-parametric statistical methods, such as Mann-Whitney U or Wilcoxon tests, can be considered for comparisons between two groups, as these methods do not require the assumption of normality. It is also necessary to consider the sample size, as normality tests on small samples can be more sensitive to small deviations from the normal distribution. If the sample size is large enough, parametric statistical tests may still be acceptable, as the sample distribution will be close to normal according to the central limit theorem. Overall, the results of this normality test provide a basis for choosing the appropriate statistical method, indicating that data analysis in the control class can use parametric tests, while in the posttest experimental class, it is necessary to consider using non-parametric methods or transforming the data first.

Because there is one group of data that is not normally distributed, the analysis of differences in posttest results between the control class and the experimental class is carried out using a non-parametric test, namely the Mann-Whitney U Test. This test is used as an alternative to the independent t-test when the normality assumption is not met. By using this approach, it is expected that the analysis results remain valid even though there is a distribution mismatch in one of the data groups. The Mann-Whitney U test results show that the test statistic value is 177.5 with a p value of 0.0076. Because the p value is smaller than 0.05, it can be concluded that there is a significant difference between the posttest scores of the control class and the experimental class. This difference indicates that the treatment given to the experimental class has an impact on student learning outcomes when compared to the control class. This significant difference shows that the learning method applied in the experimental class has a considerable influence on student learning outcomes. This could mean that the approach used was more effective in improving students' understanding compared to the method applied in the control class. Thus, the approach can be considered to be applied more widely or developed further to be more optimal. This finding also provides important implications in the field of education, especially in the selection of more effective learning strategies. If the method applied in the experimental class is proven to improve student learning outcomes, then teachers and education policy makers can consider adopting the method as part of the learning curriculum. With a more evidence-based approach like this, it is expected that the effectiveness of learning in the classroom will increase. Overall, the results of this analysis show that the learning method applied to the experimental class has a positive impact on student learning outcomes. The success of this method in significantly improving posttest scores compared to the control class is an indication that innovation in learning can provide real benefits for students. Therefore, further research can be conducted to better understand the factors that contribute to the effectiveness of this method and how its application can be improved to optimize learning outcomes.

3.1.1. The Effect of Using Augmented Reality on Critical Thinking Ability

Research has shown that Augmented Reality (AR) in learning geometry can significantly improve students' critical thinking skills. The improvement in posttest scores in the experimental class using AR-based learning compared to the control class suggests that AR enhances students' understanding of spatial concepts. Critical thinking, which includes the ability to analyze, evaluate, and construct arguments based on information, is an essential component of geometry learning. In this context, AR has the following impacts on students: (1) Interactive Observation of Spatial Figures: AR enables students to interact with and observe the shapes and characteristics of 3D geometric objects. This helps them develop a deeper understanding of spatial relationships and properties of geometry; (2) Exploration of Multiple Viewpoints: AR provides students the ability to view 3D objects from different angles. This allows students to independently compare and connect concepts, leading to a more comprehensive understanding; (3) Virtual Experiments and Problem-Solving: AR facilitates virtual experiments and allows students to solve problems related to geometry concepts. This enhances their analytical and synthetic thinking skills, crucial for critical thinking. While these benefits are evident, it is important to note the absence of statistical data in the previous discussion. A detailed statistical analysis, such as the Mann-Whitney U Test, would provide stronger empirical evidence supporting the claim that AR-based learning is more effective in improving critical thinking skills. Future research should include concrete statistical evidence to make these conclusions more academically rigorous.

3.1.2. Moderating Effect of Learning Interest on the Impact of AR on Critical Thinking

In addition to the effectiveness of AR in improving critical thinking, learning interest plays a key moderating role in this process. Research findings suggest that students who study with AR tend to show higher levels of engagement. This increased interest could serve as a moderating variable that either strengthens or weakens the effect of AR on critical thinking skills. Here's how learning interest influences the effectiveness of AR: (1) Increased Intrinsic Motivation: AR creates an engaging and enjoyable learning environment, which can spark students' intrinsic motivation to explore the subject more deeply. Students with high interest are more likely to use the interactive features of AR, thereby enhancing their critical thinking abilities; (2) Active Engagement in Learning: Students with a high level of interest in learning tend to engage more actively with AR, conducting independent exploration and collaborating with peers. This active engagement accelerates the development of a deeper understanding of the concepts; (3) Differential Impact Based on Interest: For students with low learning interest, the benefits of AR may still be present but less pronounced. Therefore, AR is more effective in improving critical thinking for students who are already motivated and interested in the subject matter. Challenges and Considerations: While learning interest can enhance the effectiveness of AR, it is essential to acknowledge the potential challenges in implementing AR in classrooms. Factors such as the technical readiness of the school, access to devices, and teacher preparedness can affect the success of AR-based learning. Additionally, strategies such as gamification, project-based challenges, or collaborative activities should be integrated to boost students' interest and engagement in the learning process.

4. Conclusion

The results of this study show that the use of Augmented Reality (AR) in learning building space has a significant positive impact on students' critical thinking skills. AR enables interactive exploration of concepts, which helps students develop analysis, evaluation and problem-solving skills. With a more real and immersive learning experience, students can better understand the relationship between spatial shapes and try various possibilities in solving geometry problems. The interactivity offered by AR also encourages students' active involvement in the learning process, so they become more interested in exploring the concepts taught. In addition, this study also shows that learning interest acts as a moderator factor that strengthens the effect of AR on critical thinking skills. The higher the students' interest in learning, the greater the benefits obtained from AR-based learning experiences. Therefore, in its implementation, it is important that educators not only adopt AR technology, but also develop learning strategies that can increase students' learning interest. Approaches such as AR-based challenges, project-based learning, and integration of gamification elements are effective ways to increase student engagement. Nevertheless, this research has some limitations that need to be considered. The scope of the study was limited to one topic and conducted in a specific classroom context, so generalization of the results to other topics or education levels needs to be done with caution. In addition, the measurement of students' interest in learning and critical thinking skills still relies on questionnaire-based instruments that are potentially influenced by student subjectivity. This study also has not explored in depth the specific features or types of AR that most contribute to improving students' critical thinking skills. Considering these limitations, this study still makes an important contribution to the field of education, especially in providing empirical evidence regarding the effectiveness of AR technology in improving students' critical thinking skills and showing the important role of learning interest as a factor that strengthens this influence. The main contribution of this study is to provide an empirical basis for the development of effective AR-based learning designs, as well as emphasizing the importance of considering affective factors such as learning interest in the design. For future research, it is recommended to explore different types of subject matter and use a mixed methods approach to gain a more thorough understanding of the mechanism of AR's influence on learning outcomes. In addition, the development and evaluation of specific AR-based learning models tailored to student characteristics and subject matter is also a potential and promising research direction.

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The preferred spelling of the word "acknowledgment" in America is without an "e" after the "g." Avoid the stilted expression "one of us (R. B. G.) thanks ...". Instead, try "R. B. G. thanks...". Put sponsor acknowledgments in the unnumbered footnote on the first page

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