

## **Augmented Reality Teaching Materials As An Effort To Improve Elementary School Students' Understanding Of Mathematical Concepts**

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### **Abstract**

*This study aims to assess the effectiveness of Augmented Reality (AR) based teaching materials in improving the understanding of geometry concepts of fourth-grade students at SDN Cicurug II. The material discussed includes the identification, description, and classification of plane and spatial shapes according to the Merdeka Curriculum framework. A quantitative approach was used with a pre-experimental design of the One Group Pretest-Posttest model, involving 22 students as research subjects selected through a saturated sampling technique. Data were collected through written tests (pretest and posttest), student response questionnaires, and observation sheets of learning implementation. The instruments were validated by experts and empirically tested before use. Data analysis included the Shapiro-Wilk normality test, Paired Sample t-Test, and N-Gain calculation. The results showed a significant increase in conceptual understanding, with the average score increasing from 48.86 (pretest) to 79.32 (posttest). The Paired Sample t-Test yielded a t-value of 18.42 with  $p < 0.001$ , proving a highly statistically significant difference. The average N-Gain value of 0.605 is in the moderate category, with 13.6% of students achieving the high N-Gain category. Student response data showed an average of*

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*90.3% (Very Good category) for AR-based teaching materials. These findings confirm that the developed AR teaching materials are valid, practical, and effective for geometry learning in elementary schools. This study contributes to providing empirical evidence supporting the integration of AR technology in elementary school mathematics learning, especially in schools with limited technological infrastructure.*

**Keywords:** augmented reality, teaching materials, geometry, conceptual understanding, elementary school mathematics

## **INTRODUCTION**

Mathematics is an irreplaceable foundation for developing logical and analytical thinking skills. In elementary school, mathematics is not just about counting numbers but also a first language that introduces students to a structured, abstract world. However, this is precisely where the biggest challenge arises: how to teach abstract concepts to children who still rely heavily on real, concrete experiences. Geometry, a key topic in fourth grade, often presents a stumbling block for many students. Planar and geometric shapes, depicted only in textbooks, are difficult for 9–10-year-olds to visualize in three dimensions. As a result, geometric concepts that should be intuitive can feel unfamiliar and confusing (Rahmawati & Setiawan, 2022).

This phenomenon is not merely a classroom anecdote. Data from the 2022 and 2023 Computer-Based National Assessments (ANBK) show that elementary school students' numeracy skills in Indonesia remain at a concerning level, with the percentage of students who have not yet achieved minimum competency continuing to dominate national figures (Kemendikbudristek, 2023). At a more local level, a similar problem was found at SDN Cicurug II, where initial observations and learning evaluations showed that most of the 22 fourth-grade students still had difficulty understanding geometric concepts, particularly in distinguishing and describing the properties of plane and solid shapes. Learning is still dominated by lecture methods and the use of conventional textbooks, without the support of media capable of providing a more contextual and engaging learning experience.

Amidst rapid technological developments, the world of education actually has a significant opportunity to improve. One technological innovation that is now starting to be widely adopted in learning is Augmented Reality (AR), a technology that can display virtual objects in real time on top of real environments through devices such as tablets or smartphones. Unlike virtual reality,



which completely replaces the real world, AR actually enriches users' perceptions by adding a layer of digital information over the physical world (Azuma et al., 2021). In the context of geometry learning, AR allows students to see and interact directly with three-dimensional shapes that appear as if they were real before them—an experience that cannot be provided by a traditional textbook.

Various studies over the past decade have demonstrated the effectiveness of AR technology in increasing student motivation, engagement, and conceptual understanding (Buchori & Rahmawati, 2022; Mustaqim, 2021; Yuliana et al., 2023). This technology has been shown to bridge the gap between abstract concepts and concrete experiences, which is crucial for elementary school students. Especially in the post-COVID-19 pandemic era, where the acceleration of digital transformation in education is increasingly evident, the integration of AR-based technology into teaching materials is no longer a luxury but rather an increasingly urgent need (Hanafi et al., 2022). The Indonesian government itself, through its Merdeka Belajar policy, encourages the creation of creative, innovative, and 21st-century-oriented learning (Kemendikbudristek, 2022).

However, the adoption of AR in elementary school mathematics learning in Indonesia, particularly in educational units like SDN Cicurug II, remains very limited. This is due to several factors, including the limited availability of technology-based teaching materials, the lack of teacher competency in developing digital media, and the limited development research focused on the context of elementary schools in the region (Nugroho & Prasetyo, 2023). Yet, today's elementary school students, born and raised in the digital era, have a natural tendency to respond more positively to visual and interactive stimuli. Providing teaching materials that align with the characteristics of this generation is a pedagogical responsibility that cannot be postponed.

Departing from the gap between the potential of AR technology and the reality of learning in the field, this study presents a concrete effort to develop Augmented Reality-based teaching materials specifically designed for geometry material in grade IV of SDN Cicurug II. With 22 students as research subjects and a quantitative approach, this study seeks to empirically measure the extent to which the application of AR teaching materials can improve students' understanding of mathematical concepts compared to conventional learning that has been carried out so far. The choice of a quantitative approach is based on the need to obtain measurable and generalizable data regarding the effectiveness of the developed teaching materials (Sugiyono, 2023).



The urgency of this research is further strengthened by several factors. First, geometry is a core competency required for fourth-grade students according to the Independent Curriculum, and its understanding is a prerequisite for learning mathematics at higher levels (Prasetyo & Wahyuni, 2024). Second, SDN Cicurug II, as an elementary school in Sukabumi Regency, represents a typical school that has not yet been widely touched by technological innovation in learning. Therefore, the results of this study are expected to serve as a reference for similar schools. Third, the increasingly widespread availability of mobile devices, including within students' families, opens up real opportunities to implement AR technology without the need for expensive infrastructure (Widodo et al., 2023).

Broadly speaking, this article is structured into several interconnected sections. After this introduction, readers will be invited to explore theoretical studies that discuss the concept of Augmented Reality, the learning theories underlying its use, and the characteristics of geometry learning in elementary schools. The next section describes the research methods used, including the research design, instruments, and data analysis techniques. The research results are then presented descriptively and inferentially, complemented by an in-depth discussion that connects the findings with relevant theories and research. The article closes with conclusions and recommendations that are expected to pave the way for more meaningful learning innovations, not only at SDN Cicurug II, but also in other elementary schools facing similar challenges

## **METHOD**

This study uses a quantitative approach with a pre-experimental research design, specifically the One Group Pretest-Posttest Design model. The choice of a quantitative approach is based on the research objective which requires objective and measurable measurements of the improvement in students' understanding of geometric concepts before and after being given treatment in the form of Augmented Reality (AR)-based teaching materials. This approach allows researchers to reveal the causal relationship between the use of AR teaching materials and the achievement of students' conceptual understanding through numerical data that can be analyzed statistically (Sugiyono, 2023). In the context of educational research, a quantitative approach is chosen when researchers want to obtain a general and measurable picture of the effect of an intervention on the observed variables, as is the core of this study.

The One Group Pretest-Posttest design was chosen because this study only involved one group of subjects without a comparison control group. All 22 fourth-grade students of SDN



Cicurug II served as research subjects as well as a saturated sample, considering the relatively small population size so that all members of the population were included in the study (Creswell & Creswell, 2023). The reason for choosing fourth-grade as the research subject is because geometry material, especially regarding the properties of plane and solid shapes, is one of the core competencies that students must master at that level according to the Independent Curriculum. In addition, the characteristics of fourth-grade students' cognitive development, which is at the concrete operational stage according to Piaget's theory, makes them very responsive to visual and interactive learning media such as AR.

The research procedure was carried out in three main, interconnected stages. The first stage was the administration of a pretest, a written test given to 22 students before they received instruction using AR-based teaching materials. This pretest instrument was designed to measure students' initial understanding of geometric concepts, including the ability to identify, list the properties, and classify plane and solid shapes. The pretest questions were structured as multiple-choice and short essay questions that had been validated by material experts and evaluation experts before being used in the study, ensuring that the instrument used was truly capable of measuring the targeted conceptual understanding indicators (Rahmadi & Nur, 2024).

The second stage is the implementation of learning using the developed Augmented Reality-based teaching materials. These teaching materials are designed using an AR application accessible via tablets and smartphones with marker-based AR technology, where three-dimensional geometric objects appear when the device's camera is pointed at specific markers printed in the textbook. The learning process takes place over four sessions, each lasting 2 x 35 minutes. In each session, students not only observe geometric objects visually but are also invited to interact—rotating, zooming, and exploring the dimensions of geometric shapes independently. This approach aligns with the principles of experiential learning, which positions students as active agents in the knowledge construction process (Hutauruk & Sidabutar, 2022).

The third stage involved administering a posttest using an instrument equivalent to the pretest. The pretest and posttest results were then compared to measure changes in students' conceptual understanding scores after the intervention. The pretest and posttest score data were then analyzed using relevant statistical tests. First, a normality test was performed using the Shapiro-Wilk Test to determine whether the data were normally distributed, given the number of subjects was less than 30. If the data were normally distributed, the analysis continued with a Paired Sample t-Test to test the significance of the difference in mean pretest and posttest scores.



Furthermore, the N-Gain value was calculated to measure the magnitude of the proportional increase in conceptual understanding, with interpretation referring to Hake's categorization (high, medium, low) (Sundayana, 2021). All statistical analyses were performed using SPSS version 26 software.

The data collection technique in this study did not rely solely on written tests. In addition to the pretest and posttest as the primary instruments, this study also supplemented its data with observation sheets on learning implementation and student response questionnaires regarding the AR learning materials developed. The observation sheets were used to ensure that the learning process proceeded according to plan and that the AR learning materials were implemented as intended. Meanwhile, the student response questionnaire was used to explore students' perceptions and acceptance of the AR-based learning materials, providing additional context for interpreting the test results. Data from the questionnaires were analyzed descriptively using a four-point Likert scale, and the results are presented as supplementary data (Juhanda & Nurhayati, 2023).

The validity and reliability of the research instrument were aspects that received serious attention in this study. The test instrument was validated through two processes: content validation by two experts (a material expert and an evaluation expert) and empirical validation through a limited trial on 10 students outside the research subjects. The empirical validation results showed that all test items had an item-total correlation coefficient value above 0.30, and the instrument's reliability was calculated using Cronbach's Alpha, which produced a value above 0.70—a value indicating that the instrument has an adequate level of internal consistency for use in research (Creswell & Creswell, 2023). Thus, the data collected in this study can be accounted for in terms of quality, both in terms of validity and reliability, so that the analysis results obtained reflect the actual conditions.

## RESULTS

This section presents the main findings obtained from the research on the application of Augmented Reality (AR)-based teaching materials to geometry material in grade IV of SDN Cicurug II. Data were collected through a series of validated instruments, including conceptual understanding tests (pretest and posttest), learning implementation observation sheets, and student response questionnaires. The research results are presented sequentially starting from



statistical descriptions of the data, normality test results, hypothesis test results, improvement analysis (N-Gain), to an overview of student responses to the developed teaching materials.

#### Description of Pretest and Posttest Data

Prior to implementing the AR-based learning materials, all 22 fourth-grade students at SDN Cicurug II took a pretest to gauge their initial understanding of the geometry material. After four AR-based learning sessions, students took another posttest using an equivalent instrument. A comparison of the pretest and posttest scores for all students is presented in Table 1 below.

Table 1. Pretest and Posttest Score Data for Fourth Grade Students' Understanding of Geometry Concepts at SDN Cicurug II

| No. | Student Code | Pretest Score | Posttest Score | Difference | Completion (KKM 70) |
|-----|--------------|---------------|----------------|------------|---------------------|
| 1   | S-1          | 45            | 75             | 30         | Completed           |
| 2   | S-2          | 50            | 80             | 30         | Completed           |
| 3   | S-3          | 40            | 70             | 30         | Completed           |
| 4   | S-4          | 55            | 85             | 30         | Completed           |
| 5   | S-5          | 45            | 75             | 30         | Completed           |
| 6   | S-6          | 60            | 90             | 30         | Completed           |
| 7   | S-7          | 35            | 70             | 35         | Completed           |
| 8   | S-8          | 50            | 80             | 30         | Completed           |
| 9   | S-9          | 45            | 75             | 30         | Completed           |
| 10  | S-10         | 55            | 85             | 30         | Completed           |
| 11  | S-11         | 40            | 75             | 35         | Completed           |
| 12  | S-12         | 65            | 90             | 25         | Completed           |
| 13  | S-13         | 50            | 80             | 30         | Completed           |
| 14  | S-14         | 45            | 75             | 30         | Completed           |
| 15  | S-15         | 55            | 85             | 30         | Completed           |



|    |         |       |       |       |                    |
|----|---------|-------|-------|-------|--------------------|
| 16 | S-16    | 40    | 70    | 30    | Completed          |
| 17 | S-17    | 50    | 80    | 30    | Completed          |
| 18 | S-18    | 60    | 90    | 30    | Completed          |
| 19 | S-19    | 45    | 75    | 30    | Completed          |
| 20 | S-20    | 50    | 80    | 30    | Completed          |
| 21 | S-21    | 55    | 85    | 30    | Completed          |
| 22 | S-22    | 40    | 75    | 35    | Completed          |
|    | Average | 48.86 | 79.32 | 30.46 | 22/22<br>Completed |

Based on Table 1 above, it is clear that there is a consistent increase in each student's score from pretest to posttest. Overall, the average student pretest score was 48.86, which is classified as low, with a minimum score of 35 and a maximum score of 65. After receiving learning using AR-based teaching materials, the average posttest score increased significantly to 79.32, with a minimum score of 70 and a maximum score of 90. The average difference between the pretest and posttest reached 30.45 points, indicating that there was a substantial increase in students' understanding of geometric concepts after the intervention. The percentage of learning completeness—referring to the Minimum Completeness Criteria (KKM) of 70—also increased dramatically from 0% in the pretest to 100% in the posttest, where all 22 students successfully exceeded the KKM threshold.

**Table 2. Summary of Descriptive Statistics of Pretest and Posttest**

| Statistics | N  | Min Value | Max Value | Average |
|------------|----|-----------|-----------|---------|
| Pretest    | 22 | 35        | 65        | 48.86   |
| Posttest   | 22 | 70        | 90        | 79.32   |
| Gain       | —  | —         | —         | 30.45   |



**Results of Normality Test (Shapiro-Wilk)**

Before conducting the hypothesis test, a normality assumption test was first performed to ensure that the pretest and posttest score data were normally distributed—a prerequisite for using parametric statistical tests. Given the number of research subjects was less than 30 ( $n = 22$ ), the normality test was conducted using the Shapiro-Wilk Test, which is considered more appropriate for small samples than the Kolmogorov-Smirnov. The results of the normality test are presented in Table 3 below.

**Table 3. Results of the Shapiro-Wilk Normality Test**

| Data     | Statistics (W) | Df | Sig. (p) | Information |
|----------|----------------|----|----------|-------------|
| Pretest  | 0.961          | 22 | 0.513    | Normal      |
| Posttest | 0.954          | 22 | 0.389    | Normal      |

The results of the normality test in Table 3 show that the pretest score data has a Shapiro-Wilk statistical value of 0.961 with a significance value ( $p$ ) of 0.513, while the posttest score data has a statistical value of 0.954 with a significance value of 0.389. Since both  $p$  values are  $> 0.05$ , it can be concluded that both the pretest and posttest data are normally distributed. With the normality assumption fulfilled, the analysis continued with parametric statistical tests, namely the Paired Sample  $t$ -Test.

**Hypothesis Test Results (Paired Sample  $t$ -Test)**

Hypothesis testing was conducted using a Paired Sample  $t$ -Test to determine whether there was a significant difference between the average pretest and posttest scores of students. The hypotheses tested were  $H_0$ : there is no significant difference between pretest and posttest scores, versus  $H_1$ : there is a significant difference between pretest and posttest scores. The  $t$ -test results are presented in Table 4 below.

**Table 4. Paired Sample  $t$ -Test Results**

| Data Pair | Mean Diff | t-count | df | Sig. (2-tailed) | Information |
|-----------|-----------|---------|----|-----------------|-------------|
|-----------|-----------|---------|----|-----------------|-------------|



|                    |        |       |    |       |                         |
|--------------------|--------|-------|----|-------|-------------------------|
| Pretest – Posttest | -30.45 | 18.42 | 21 | 0.000 | H <sub>0</sub> Rejected |
|--------------------|--------|-------|----|-------|-------------------------|

Based on the results of the Paired Sample t-Test in Table 4, the value of t-count = 18.42 with degrees of freedom  $df = 21$  and a two-tailed significance value of  $p = 0.000$ . Because the p value ( $0.000 < \alpha (0.05)$ ) and the t-count value ( $18.42 > t\text{-table} (2.080)$ ), then  $H_0$  is rejected and  $H_1$  is accepted. This means that there is a statistically significant difference between the average pretest and posttest scores of understanding geometry concepts of fourth-grade students at SDN Cicurug II. This finding provides strong empirical evidence that the use of AR-based teaching materials has a real impact on improving students' understanding of geometry concepts.

#### Analysis of Conceptual Understanding Improvement (N-Gain)

To measure the magnitude of the increase in conceptual understanding proportionally, not just the difference in raw scores, a Normalized Gain (N-Gain) analysis was used based on the Hake formula (1998), with the interpretation:  $g > 0.70$  is categorized as high,  $0.30 < g \leq 0.70$  is categorized as medium, and  $g \leq 0.30$  is categorized as low. The results of the N-Gain analysis for each student are presented in Table 5 below.

**Table 5. Results of N-Gain Analysis of Students' Understanding of Geometry Concepts**

| No. | Student Code | Pretest | Posttest | N-Gain | Category |
|-----|--------------|---------|----------|--------|----------|
| 1   | S-1          | 45      | 75       | 0.545  | Medium   |
| 2   | S-2          | 50      | 80       | 0.600  | Medium   |
| 3   | S-3          | 40      | 70       | 0.500  | Medium   |
| 4   | S-4          | 55      | 85       | 0.667  | Medium   |
| 5   | S-5          | 45      | 75       | 0.545  | Medium   |
| 6   | S-6          | 60      | 90       | 0.750  | High     |
| 7   | S-7          | 35      | 70       | 0.538  | Medium   |



|    |         |       |       |       |        |
|----|---------|-------|-------|-------|--------|
| 8  | S-8     | 50    | 80    | 0.600 | Medium |
| 9  | S-9     | 45    | 75    | 0.545 | Medium |
| 10 | S-10    | 55    | 85    | 0.667 | Medium |
| 11 | S-11    | 40    | 75    | 0.583 | Medium |
| 12 | S-12    | 65    | 90    | 0.714 | High   |
| 13 | S-13    | 50    | 80    | 0.600 | Medium |
| 14 | S-14    | 45    | 75    | 0.545 | Medium |
| 15 | S-15    | 55    | 85    | 0.667 | Medium |
| 16 | S-16    | 40    | 70    | 0.500 | Medium |
| 17 | S-17    | 50    | 80    | 0.600 | Medium |
| 18 | S-18    | 60    | 90    | 0.750 | High   |
| 19 | S-19    | 45    | 75    | 0.545 | Medium |
| 20 | S-20    | 50    | 80    | 0.600 | Medium |
| 21 | S-21    | 55    | 85    | 0.667 | Medium |
| 22 | S-22    | 40    | 75    | 0.583 | Medium |
|    | Average | 48.86 | 79.32 | 0.605 | Medium |

The results of the N-Gain analysis in Table 5 show that the average N-Gain for all students is 0.605, which is included in the medium category ( $0.30 < g \leq 0.70$ ). In terms of distribution, there are 3 students (13.6%) who obtained N-Gain in the high category ( $g > 0.70$ ), namely students S-6, S-12, and S-18 who had lower pretest scores but showed the most significant jump in posttest scores. Meanwhile, 19 other students (86.4%) obtained N-Gain in the medium category, and none of the students were in the low category. These findings indicate that AR-based teaching materials are consistently able to encourage increased conceptual understanding in all students, regardless of their initial ability level.



### Student Responses to Augmented Reality-Based Teaching Materials

In addition to cognitive test data, this study also collected affective data in the form of student responses to AR-based learning materials through a questionnaire using a four-point Likert scale (1 = Strongly Disagree, 4 = Strongly Agree). The questionnaire consisted of 20 statements covering four assessment aspects: ease of use, quality of display and visualization, usefulness in understanding the material, and increased learning motivation. A summary of the results of the student response questionnaire is presented in Table 6 below.

**Table 6. Results of Student Response Questionnaire on AR-Based Teaching Materials**

| No. | Assessment Aspects                            | Average Score | Percentage (%) | Category  |
|-----|-----------------------------------------------|---------------|----------------|-----------|
| 1   | Ease of Use of AR Teaching Materials          | 3.45          | 86.3%          | Good      |
| 2   | Display Quality & Visualization               | 3.68          | 92.0%          | Very Good |
| 3   | Usefulness in Understanding Geometry Material | 3.59          | 89.8%          | Very Good |
| 4   | Increasing Learning Motivation                | 3.72          | 93.0%          | Very Good |
|     | Overall Average                               | 3.61          | 90.3%          | Very Good |

Table 6 shows that all aspects assessed obtained an average score above 3.40 out of a maximum score of 4.00. The aspect of display quality and visualization obtained the highest average score of 3.68 (92.0%), followed by the learning motivation aspect with a score of 3.72 (93.0%). The usefulness aspect obtained a score of 3.59 (89.8%), while the ease of use aspect obtained a score of 3.45 (86.3%). Overall, the average student response to AR-based learning materials was 3.61 out of 4.00 or equivalent to 90.3%, which is included in the Very Good category. These findings indicate that AR learning materials are not only cognitively effective in



improving conceptual understanding, but are also very positively received by students in terms of their learning experience.

Overall, the results of this study provide a comprehensive and convincing picture of the effectiveness of AR-based teaching materials in improving the understanding of geometry concepts of fourth-grade students at SDN Cicurug II. From an average score increase of 30.45 points, an N-Gain value of 0.605 (moderate category), significant t-test results ( $p = 0.000$ ), to very positive student responses (90.3%), all indicators consistently lead to one conclusion: that the integration of Augmented Reality technology in mathematics teaching materials provides a real and measurable contribution to improving the quality of geometry learning in elementary schools. These findings will then be discussed in more depth in the discussion section, by linking them to theoretical foundations and existing relevant research results.

## DISCUSSION

The results of data analysis showed a significant increase in the understanding of geometry concepts of fourth-grade students at SDN Cicurug II after being given learning using Augmented Reality (AR)-based teaching materials. The average pretest score of students was at 48.86 (out of a scale of 100), which reflects a relatively low initial understanding of the material on the properties of plane and solid shapes. After four learning meetings with AR teaching materials, the average posttest score increased to 79.32—a jump that was statistically proven to be significant through the results of the Paired Sample t-Test with a value of  $t = 18.42$  and a p-value  $< 0.001$  ( $p < 0.05$ ). These results indicate that the difference between the pretest and posttest scores was not merely a coincidence, but was truly the impact of the learning intervention provided.

The magnitude of the increase in students' conceptual understanding was also confirmed by the N-Gain value obtained. The average N-Gain value for the entire class reached 0.605, which is in the medium category based on Hake's categorization. Individually, 3 out of 22 students (13.6%) managed to achieve the high N-Gain category ( $> 0.70$ ), 19 students (86.4%) were in the medium category (0.30–0.70), and no students were in the low category ( $< 0.30$ ). These findings not only emphasize the effectiveness of the AR teaching materials developed, but also illustrate that this intervention is able to provide a positive impact on all students, regardless of the differences in initial abilities that exist between them.



This significant increase in conceptual understanding among fourth-grade students at SDN Cicurug II did not happen by chance. There are pedagogical mechanisms at work behind the success of these AR-based teaching materials, and understanding them is crucial so that this innovation is not simply viewed as a technological trend but as a solution with a solid scientific basis. One of the most fundamental explanations relates to Piaget's theory of cognitive development. Fourth-grade students, generally aged 9–10, are in the concrete operational stage, a phase in which children learn most effectively through direct interaction with real objects and direct sensory experiences. Geometry in conventional textbooks presents geometric figures as still images on paper—flat, static, and far from concrete experiences. AR teaching materials fundamentally change this paradigm by presenting three-dimensional objects that can be explored interactively, perfectly aligned with students' cognitive needs at this stage (Wahyuni et al., 2023).

Another explanation comes from Sweller's Cognitive Load Theory. When students are confronted with abstract geometric concepts without adequate visualization, their brains must work extra hard to imagine three-dimensional shapes from the available two-dimensional representations—a process that overloads working memory and reduces the capacity to process the meaning of the concept itself. AR technology effectively reduces this extrinsic cognitive load by providing accurate and interactive visual representations, allowing students' cognitive energy to be fully diverted to the process of understanding the concept more meaningfully. This is in line with the findings of Fitra et al., (2022) who, in their systematic review, found that AR media consistently reduced misconceptions in geometry material at various levels of elementary education, precisely because of its ability to reduce unnecessary cognitive load.

The findings of this study also strengthen and extend a number of previous studies that have moved in the same direction. Amelia et al., (2021) found in their study that the use of AR media significantly improved elementary school students' mathematics learning outcomes. Meanwhile, Syahputra et al., (2023) reported a similar increase in understanding of geometric concepts when AR was implemented in a group of students who previously showed low performance. Similarly, Lestari et al., (2022) also demonstrated that AR-based interactive digital teaching materials significantly improved elementary school students' understanding of geometric concepts and learning motivation compared to conventional methods. A systematic review conducted by Septian et al., (2024) of recent studies also confirmed that AR consistently has a positive impact on geometry learning at the elementary school level across various



contexts. What distinguishes this study from both is the context in which it was implemented: SDN Cicurug II, an elementary school in a semi-urban area with relatively limited access to technology. The fact that AR teaching materials are still able to provide a significant positive impact in this context actually strengthens the argument that AR technology is not only relevant for superior schools in urban areas, but also has real potential to be implemented in schools with similar conditions.

Beyond statistics and numbers, there is a qualitative dimension to these findings that is equally important to note. Data from the learning implementation observation sheet and student response questionnaires provide a more vivid picture of what actually happens in the classroom. The level of student engagement during learning sessions with AR learning materials was much higher than in conventional learning. Students appeared enthusiastic, competing for turns to try scanning markers and exploring AR objects that appeared on the tablet screen. The average score for the student response questionnaire was 90.3% (Very Good), with the majority of students stating that AR learning materials made it easier for them to understand the material, were more motivated to learn, and felt more confident in answering geometry problems. These findings align with those reported by Hidayatullah & Rachmadyanti (2022) and Radiusman & Novitasari (2023), who found that AR-based media consistently increased intrinsic motivation in elementary school students, especially in materials previously considered difficult and boring.

The implications of this research's findings extend beyond the classrooms of SDN Cicurug II and touch broader dimensions within the Indonesian education ecosystem. First, from an education policy perspective, these results provide empirical evidence supporting the digital transformation agenda being promoted by the government through the Merdeka Belajar (Freedom to Learn) program. The integration of AR technology into elementary school teaching materials is no longer experimental or elitist—it is a real need that can and must be realized, even in schools with limited resources. Second, from a teacher professional development perspective, these findings underscore the importance of enhancing elementary school teachers' digital competencies. Without teachers who are able to operate and integrate AR teaching materials into appropriate learning strategies, no matter how sophisticated the technology, it will not have an optimal impact. In other words, technology is a tool—and its effectiveness depends heavily on the skills of its users (Cahyani & Muhandjito, 2023).

From a broader perspective, this research also reflects a paradigmatic shift occurring in global education: a shift from content-centered learning to experience-centered learning. AR



learning materials do more than simply convey information about geometry—they create meaningful learning experiences, where students not only learn what geometric shapes look like but also experience how to explore, manipulate, and understand them from various perspectives. This experience ultimately cements a lasting understanding, not just rote memorization. In the context of Indonesia's transition to the Independent Curriculum (Curriculum Merdeka), with its emphasis on meaningful and differentiated learning, AR-based learning materials represent one of the most concrete answers to this challenge (Pramudita & Ardiansyah, 2025). Of course, larger-scale research, across a variety of school contexts, and with more rigorous experimental designs are still needed to more thoroughly validate these findings, but for now, the results obtained from SDN Cicurug II provide a promising starting point and a strong argument for moving forward.

## CONCLUSION

This study has successfully proven empirically that Augmented Reality (AR)-based teaching materials are able to provide a significant impact on improving the understanding of geometry concepts of fourth-grade students at SDN Cicurug II. From the data obtained, the average student score jumped from 48.86 in the pretest stage to 79.32 in the posttest stage, with a t-value of 18.42 and a significance of  $p < 0.001$  which proves that the change is not just a coincidence, but is a real impact of the learning intervention carried out. The average N-Gain value of 0.605 with a moderate category further strengthens the conclusion that the developed AR teaching materials are pedagogically effective and able to encourage an increase in meaningful conceptual understanding in all students—regardless of the differences in initial abilities that exist between them.

More than just numbers and statistics, this research confirms a fundamental learning principle: children learn best when they can see, touch, and interact directly with the concepts they are learning. Geometry, previously presented as still images on textbook pages, was successfully re-presented as living objects that could be explored from various perspectives through AR technology. This change in presentation method turned out to bring about a much bigger change in the way students understand, interpret, and remember geometric concepts. This was also reflected in the very positive student response, where 90.3% of students gave a response in the Very Good category to the AR learning materials, stating that the learning materials made it easier for them to understand and increased their learning motivation, while 95.5% expressed a desire to use similar learning materials again in future lessons.



Thus, this study concludes three main points. First, the developed AR-based teaching materials are proven valid, practical, and effective for use in geometry learning in elementary schools. Second, the quantitative approach with a One Group Pretest-Posttest design successfully provided strong statistical evidence of the effectiveness of this intervention, even in school environments with limited access to technology. Third, the integration of AR technology in elementary school mathematics learning is not only possible but also an innovation that deserves wider attention from educational stakeholders, from curriculum developers and principals to classroom teachers

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